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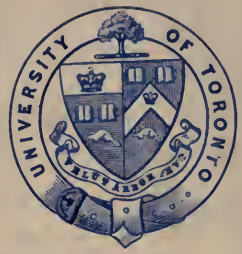

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(SECOND TREATISE)

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NOTICE.

THE present Treatise—comprehending MECHANICS, the ELEMENTS OF PRACTICAL MACHINERY, and MOVING FORCES—forms the Second Department of Natural Philosophy, according to the arrangement described in the Prefatory Notice to the LAWS OF MATTER AND MOTION.

A passage of that notice, as of general application, may appropriately be repeated here:—"In exercising a class in this and other departments of Natural Philosophy, it will be found to be of considerable importance to cause each paragraph to be mastered, or thoroughly understood, before proceeding to what follows; for the whole constitutes a structure in which each part rests on what has gone before it. The pupil should also not only *read*, but be induced to *think* on the nature of the principles which are unfolded, and led to find examples of their action in the every-day concerns of life, and the common phenomena of the universe." It is further suggested that pupils should, by the aid of small pieces of wood, cord, and other easily-procured materials, endeavour to work out with their own hands the various principles of Mechanics which are demonstrated in the following pages. It is believed that by no other means could these valuable principles be so well fixed in the memory, or have such a powerful effect in cultivating the understanding.

In the present, as in the preceding Treatise, very great pains have been taken to render the language simple and intelligible, so that the learner may find at least no technical difficulty in his path. Those who are desirous of pursuing the study of Dynamical and Mechanical science beyond the limits of these ele-

mentary works, and who possess a knowledge of Algebraic and Mathematical formulæ, are recommended to have recourse to the excellent "Treatise of Mechanics, Theoretical and Practical, by Olinthus Gregory;" the "Introduction to Natural Philosophy, by William Nicholson;" or to the Treatises of Wood, Leslie, Whewell, Potter, and Weisbach. No popular and comprehensive treatise on the properties of matter and doctrines of forces excels the well-known Elements of Physics, by Dr Neil Arnot. There are also a few compendious productions of American writers which may be consulted, particularly those of Gale, Comstock, and Bigelow, to which the Editors have to acknowledge themselves indebted for some useful hints. Engineers, millwrights, and other artisans, who require to make practical calculations, will find a small work, entitled "Brunton's Compendium of Mechanics," worthy of their attention.

CONTENTS.

	PAGE
MECHANICS—General Definitions,	7
Levers—	
First Kind of Lever,	9
Second Kind of Lever,	16
Third Kind of Lever,	18
Compound Levers,	19
Bent Levers,	21
Recapitulation of Lever Powers,	23
Animal Levers,	24
The Wheel and Axle—	
Definitions,	27
Practical Applications,	28
Pulleys—	
Fixed Pulleys,	31
Movable Pulleys,	31
Principle of the Pulley Power,	33
Combinations of Pulleys,	34
Practical Application of Pulleys,	35
The Inclined Plane—	
Definition,	36
Standards of Comparison for Inclinations,	36
Principle of the Power of Inclined Planes,	37
Rules for Calculating the Power of Inclined Planes,	38
The Wedge—	
Definitions,	41
Rules for Calculating the Powers of the Wedge,	41
Examples of Wedge Powers,	42
The Screw—	
Definitions,	43
Powers of the Screw,	43
Rules for Calculating the Powers of the Screw,	45
Examples of Screw Powers,	46

PAGE

MECHANICAL COMBINATION AND STRUCTURE—
General Explanations, - - - - - - - 47
Arched Structures, - - - - - - - 51

ELEMENTS OF PRACTICAL MACHINERY — GENERAL DEFINITIONS, - - - - - - - - 53
Shafts, - - - - - - - - - - 55
Pedestals, or Plummet-blocks, for Horizontal Shafts, - - 56
Hangers, or Suspension-bearings, - - - - - 57
Steps, or Bearings, for Vertical Shafts, - - - - - 58
Couplings for Shafts, - - - - - - - 58
Toothed Wheels, - - - - - - - - 59
Pulleys, - - - - - - - - - 60
Ratchet-wheels, - - - - - - - - 60
Cranks, - - - - - - - - - 60
Connecting-rods, - - - - - - - - 61
Eccentrics, - - - - - - - - - 62
Altering the Direction of Motion, - - - - - 63
Altering the Velocity of Motion, - - - - - 64
Preserving the Direction of the Original Motion, - - - 65
Transmission of Power from one Point to another, - - 65
Changing or Varying the Velocity of Motion, - - - - 66
Intermittent and Alternating Motions, - - - - 67
Accumulating and Equalising of Power, - - - - 71
Regulation of Power, - - - - - - - 74
Engaging and Disengaging Machinery, - - - - - 75

OBSTACLES TO MOTION—
Friction, - - - - - - - - - 76
Uses of Friction, - - - - - - - - 79
Resistance of Air and Water, - - - - - - 80

MOVING FORCES—
Human Labour, - - - - - - - - 81
Horse's Power—Draught, - - - - - - - 83
Water-power, - - - - - - - - 87
Steam-power and the Steam-engine, - - - - - 89
Boilers, - - - - - - - - - 97

MECHANICS.

GENERAL DEFINITIONS.

1. The application of the laws of motion and forces to objects in nature or contrivances in the arts, forms the branch of Natural Philosophy usually treated under the head MECHANICS, MECHANICAL POWERS, or ELEMENTS OF MACHINERY.

2. The original signification of the word *machine*—which is the root of the various terms *mechanic, mechanical,* and so forth—was art, contrivance, ingenuity, or, in general, the means of bringing about an effect; hence a machine, in its widest acceptation, is an engine or instrument devised to produce an effect.

3. When the term "mechanics," or "mechanical," is applied to the action of forces—as mechanical powers—it is meant that certain powers are exerted, or motion produced, by the action of particles or masses of matter, solid or fluid, one upon another. Thus, *mechanical action* is applied to the action of forces that produce no change in the constitution of bodies, and is therefore distinguished from *chemical, vital,* or any other species of action. For example, the pounding of a piece of limestone to powder is strictly mechanical, whether it be effected by the blows of a hammer, or by the silent agency of running water; but the reduction of limestone to a similar state by sulphuric acid is chemical. In the former case, all the elements of the original limestone remain in the powder; whereas in the latter, it is converted by the action of the acid into a very different compound.

4. In Natural Philosophy, machines are usually distinguished as *simple* or *complex.* A simple machine is equivalent to a tool or instrument, as a spade or lever; a complex machine is

an engine in which different parts or various tools combine to produce the required effect. In ordinary language, these distinctions are not very minutely attended to, though indispensable to the precision of science. *Mechanics* is the term commonly employed to comprehend the science which treats of machines, whether theoretically of their powers, or practically of their application and construction.

5. Machines are, under all denominations or circumstances, only instruments through which power may be made to act. They only convey, regulate, or distribute the force or power which is communicated to them from some source of motion, and never create or generate power. But although a machine does not create power, or give more power than it has received, it practically applies the power which has been communicated to it, in so convenient and easy a manner, that a result ensues almost as surprising as if it had actually generated the whole or a portion of the power it exhibits.

6. The main purpose required in mechanical operations is to overcome, oppose, or sustain a certain resistance or force. This purpose is obtained by applying another species of force. According to the usual phraseology, the resistance or force to be overcome is called the *weight* or resistance, and the force which is applied is called the *power*.

7. The ability of applying force by the human hands, without the aid of instruments or machines, is very limited. In almost all our operations of art, it is found necessary to call in the aid of instruments or machines of some kind. All the instruments which mankind have adopted for their purposes —from a piece of stick, with which the savage scratches the ground as a plough, to the most elegantly-finished piece of mechanism—act upon certain fixed principles in nature, which a long course of experience and scientific investigation has developed.

8. The mechanical powers which exhibit the working of these principles are commonly reckoned three in number —namely,

1. The LEVER.
2. The PULLEY.
3. The INCLINED PLANE.

These may be called the PRIMARY MECHANICAL POWERS; and from two of them—the Lever and Inclined Plane—other three are formed, as follow—

1. WHEEL and AXLE, from the LEVER.
2. WEDGE, from the INCLINED PLANE.
3. SCREW, from the INCLINED PLANE.

These may be called the SECONDARY MECHANICAL POWERS.

The six altogether form the most usually-occurring elements of complex machinery.

LEVERS.

9. The lever is one of the most important and extensively used of all the mechanical powers, and its operation exhibits some of the leading principles in mechanics.

10. A lever is a rod, or bar of iron, wood, or any other material, which is movable upon or about a prop or fulcrum, or about a fixed axis. It is called a *lever*, from a French word signifying to raise, the raising of weights being one of its frequent applications.

11. Three elements contribute to the operation of the lever —the *power*, the *fulcrum*, and the *weight*. The power is the force applied, the fulcrum is the prop or support, and the weight is the resistance or burden to be lifted. The terms *power* and *weight* have merely a reference to the manner in which the machine is used; strictly, both the power and weight are *forces* the same in character and action.

12. There are three kinds of levers, differing according to the relative situation of the power, fulcrum, and weight. Each of these kinds consists of a straight bar, and in theoretical calculations is supposed to be in itself destitute of any gravity or degree of heaviness. In theory, also, the forces which are applied are supposed to act at *right angles* to the fulcrum.

13. In the first or most simple kind of lever, "the fulcrum is disposed between the power and the weight." In the second kind, "the weight is disposed between the power and the fulcrum." In the third kind, "the power is disposed between the weight and the fulcrum."

FIRST KIND OF LEVER.

14. In the first kind of lever, "the fulcrum is disposed between the power and the weight." Fig. 1 is an example. A to B is a straight bar, resting on a prop or fulcrum F. From A to F is the long arm of the lever, and from F to B is the short arm. P is the power, or a certain force drawing down the extremity of the long arm at A. W is the weight suspended from the extremity of the

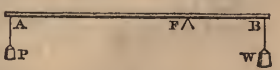

Fig. 1.

short arm at B. The object is to cause P, which is supposed to be a small weight, to balance or overcome W, which is supposed to be a weight much heavier. Practically, the force of a man pressing upon the extremity of the handle of the lever at A, will effect with ease, in lifting the heavy weight W, what it would require a much greater force to accomplish by pressing upon the long arm at a point nearer the fulcrum.*

15. This is more clearly exemplified in fig. 2, which represents a lever placed conveniently for raising a square block W, which is the weight. On pressing down the extremity of the long arm of the lever at A, the point of the short arm B raises the block. F is an object lying on the ground to press against as the fulcrum. As in the case of fig. 1, "the force of a man pressing upon the extremity of the handle at A, will effect with ease, in lifting the weight W, what it would require a much greater force to accomplish by pressing upon the long arm at a point half way betwixt A and the fulcrum."

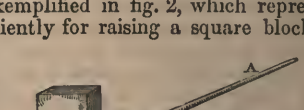

Fig. 2.

16. The principle in mechanics which produces this phenomenon is very simple, and is explained by what is called the LAW OF VIRTUAL VELOCITIES, or, from its general application, the GOLDEN RULE OF MECHANICS.

17. This law or rule is, THAT A SMALL WEIGHT, DESCENDING A LONG WAY IN ANY GIVEN LENGTH OF TIME, IS EQUAL IN EFFECT TO A GREAT WEIGHT DESCENDING A PROPORTIONALLY SHORTER WAY IN THE SAME SPACE OF TIME. In other words, what is gained in velocity or time is lost in expenditure of power.

18. Another way of stating this important law is as follows:—IN THE CASE OF EQUILIBRIUM, IF A MOTION BE GIVEN TO THE MECHANICAL POWER, THEN THE POWER MULTIPLIED BY THE SPACE THROUGH WHICH IT MOVES, IN A VERTICAL DIRECTION, WILL BE EQUAL TO THE WEIGHT MULTIPLIED BY THE SPACE THROUGH WHICH IT MOVES IN A VERTICAL DIRECTION.

* *Note* 1.—Properly speaking, the power does not sustain the weight, for both are supported by the fulcrum; the power, in the case of equilibrium, only prevents the weight from producing a motion of rotation.

Note 2.—In every machine, simple or complex, besides the power required to balance the resistance, there must be some additional power applied in order to produce motion, or overcome the inertia of rest of the body.

19. This principle, which applies to every mechanical movement in the case of equilibrium, has been illustrated by a reference to the property of attraction of gravitation. What is called weight, is only an effect of gravity on the atoms of matter. In figurative language, every atom is drawn towards the earth by an invisible line or cord of attraction; and when one atom rises or falls ten inches, the same quantity of attraction is drawn out from, or sent back, to the earth, as if ten atoms were to rise or fall only one inch.

20. Thus, by a proper mode of applying the power, we may cause a weight of one pound, by moving through a space of ten feet, to raise another weight of ten pounds, moving through a space of one foot; or (the reverse) by a weight of ten pounds moving through the space of one foot, we may make a single pound move through the space of ten feet. But by none of the mechanical powers shall we be able, by moving a weight of ten pounds through one foot, to move a single pound through eleven feet; nor, by a single pound moving through a space of nine feet, shall we be able to raise a weight of ten pounds through one foot.

21. Neither by the power of the lever, therefore, nor by any other of the mechanical powers, can we make any absolute increase of the power which is applied. In other words, the quantity of power expended in any great and instantaneous effort, is exactly the amount of the power which has been previously accumulated. All that we can do to procure mechanical advantage, is to accommodate the velocity, force, or direction of the applied power, to the purposes which we may have in view.

22. To apply this principle to the lever, fig. 1 or 2, a small force at A is equal to double the force exerted at a point half way betwixt A and the fulcrum, yet in both cases the same amount of mechanical power is expended. A slight push downwards at A, by being continued for one minute, is equal to a push of a double force of half the speed, at a point half way towards the fulcrum, continued for the same time. Any amount of force, therefore, can be exerted with ease at the extremity of the long arm of the lever, provided we choose to make the arm long enough and strong enough.

23. It may possibly be said that it would be as expeditious to push down the extremity of the long arm of the lever, as to push down the arm at a point nearer the fulcrum. Practically, in small levers this may be the case; but when levers of considerable length have to be used, and a succession of depressions and raisings are necessary, it will be found that more time is spent in working with a long than a short lever. For when

the sweep of the lever is inconveniently long, the person using it has to move his body quickly up and down over a larger space, and is sooner fatigued. For this reason, although a boy with a long lever may balance as great a weight as a man with a shorter one, yet, in raising weights successively by it, the boy would be sooner fatigued.

24. It is a general rule, that "the force of the lever increases in proportion as the distance of the *power* from the *fulcrum* increases, and diminishes in proportion as the distance of the *weight* from the fulcrum increases." In making calculations to ascertain the proportions to be observed betwixt the power and the weight, regard must be paid to the respective lengths of the long and short arms of the lever. We must also fix what are to be the units of weight and distance, and let them be the same on both ends. If we state inches to be the unit of length of the short arm, inches must be the unit of length of the long arm; and, in the same manner, if ounces be made the unit of weight of the short arm, ounces must be made the unit of power of the long arm.

25. Rule.—Multiply the weight by its distance from the fulcrum; then multiply the power by its distance from the same point, and if the products are equal, the weight and the power will balance each other.

26. Example I.—Suppose a weight of 100 pounds on the short arm of a lever, at the distance of 8 inches from the fulcrum, then another weight or power of 8 pounds would be equal to this, at the distance of 100 inches from the fulcrum. Because 8 multiplied by 100 produces 800, and 100 multiplied by 8 produces 800—and thus the weight and the power would mutually counteract each other.

27. Example II.—Suppose we wish to calculate what power should be employed at the end of the long arm of a lever to balance a given weight at the end of the short arm. We multiply the weight by the length of its arm: this gives us a product; then divide that product by the number of inches in the long arm, and the result or quotient is the power. Thus a weight of 10 pounds multiplied by 10 inches, as the length of the short arm, gives a product of 100. If the length of the long arm be 20, we find how many twenties are in 100—and there being 5, consequently 5 pounds is the power. In this instance the mechanical advantage is two to one—that is, the power is half as great as the weight.

28. The common spade used in delving in gardens offers a similar example of simple lever power, when employed in raising the earth from its place to turn it over. Fig. 3 represents an equally familiar example—namely, a wood-sawyer

or carpenter moving a log of timber from its place, by means of a long pole or beam of wood. Stone masons use a lever of iron of this description, called a crow-bar.

Fig. 3.

29. The ancient Egyptians were acquainted with the power of the lever, and employed it to raise the large blocks of stone of which the Pyramids are composed. The lever used by them, however, was of a rude description, and required many men to wield it. According to Herodotus, a Greek historian, who writes of Egypt, it consisted of a beam of wood, fixed by a joint or axle on an upright frame, which was the fulcrum. The longer arm of this lever was several times the length of the shorter arm. To lift each block, it was necessary to employ

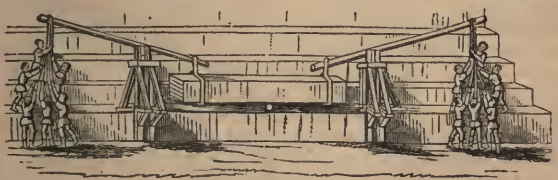

Fig. 4.

two of these levers, with ropes attached, one lever at each end of the block. A number of men were employed to pull the ropes, as represented in fig. 4. After the block was raised one step up on the exterior of the pyramid, the levers were lifted up another step higher, and the block raised to their level. In this primitive and tedious manner were the Pyramids of Egypt erected.* In modern times, the principle of the lever

* To erect one pyramid alone, called the Great Pyramid, required the work of 100,000 men for twenty years ; and although these men were

is employed in a much more speedy and efficacious manner in raising or lowering blocks of stone for masonry, or in loading and unloading bales of goods in commerce, by means of a machine called a crane.

30. The power of the first kind of lever is frequently seen to operate in machines or instruments having two arms. The most common examples of this nature are pincers, scissors, and similar instruments. In the pair of scissors here represented, the two limbs are seen to be joined together with a rivet at the centre, which is the fulcrum of both.

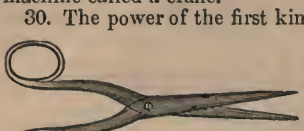

Fig. 5.

31. A common scale-beam for weighing, used by shopkeepers, is an example of the first kind of lever formed with two arms of equal length, and suspended over the centre of gravity, so that the two extremities balance each other. See fig. 6. S is a string or line suspending the beam A B at a central point F, which is the fulcrum. The point of suspension or pivot is sharpened to a thin edge, so as to allow the arms to rise or fall with as little friction as possible when anything is put in the scales.

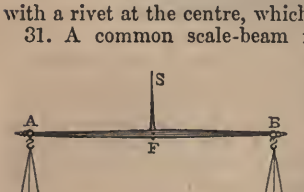

Fig. 6.

32. There is another kind of balance, called a *steelyard*, which consists of a lever with arms of unequal length, and acts upon the principle of distance from the fulcrum on the long arm compensating for weight on the short arm, as defined in paragraphs 26 and 27. Fig. 7 is a representation of the steelyard balance. C is the fulcrum or pivot by which the beam is suspended, and freely plays as on an axis. A is the short arm, and the opposite end is the long arm. W is the scale for the reception of the article to be weighed. The long arm is graduated into divisions by marks, each mark denoting by a figure a certain number of pounds or ounces. P is a weight of a certain heaviness, and being movable by a ring, it can be slipped along the bar to any required point. The same weight

compelled to work without wages, like slaves, the expense incurred was enormous. In the present day, the steam-engines of England, by a united effort, could lift the whole of the stones of the Great Pyramid into their places in about twenty hours.

is always used, and thus constitutes one of the principal conveniences of this kind of balance. In proportion as the article

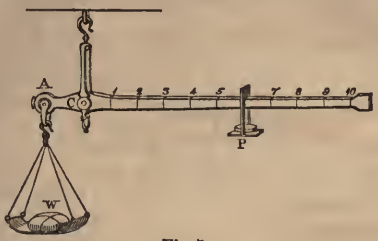

Fig. 7.

to be weighed in the scale W is heavy, so is the weight P slipped along to a greater distance from the fulcrum; and when it is brought to a point where it balances the article, the figure on the bar at that point indicates the amount of the weight. If P be one pound, and if, when suspended from the division at 6, it balance the weight at W, it is evident that the weight will be six times P, or 6 pounds; that is, supposing that each division on the long arm is equal to the length of the short arm, or that C 1 is equal to C A. And so on with all the other divisions.

33. The steelyard, though not so ancient as the common balance, is of considerable antiquity. It was used by the Romans, and has long been in use among the Chinese. Neither the common balance nor the steelyard is suitable for showing the varying weight or heaviness of an article at different latitudes of the earth's surface, because the weights employed are equally affected with the attraction of gravitation and centrifugal force, as the article to be weighed. For this reason, the difference of weight resulting from the causes mentioned, can only be demonstrated by a balance formed of a spring of elastic metal. By suspending the article from the spring, it pulls it out to a certain extent, and so indicates the weight on a graduated scale on the instrument. As the spring acts the same in all latitudes, it serves as a fixed or unalterable power, while the article to be weighed is liable to an alteration in its weight or heaviness according as it is brought near, or carried from, the equator.*

* See explanation of variability of weight in paragraphs 48 and 49, LAWS OF MATTER AND MOTION.

SECOND KIND OF LEVER.

34. In the lever of the second kind, the weight is placed between the power and the fulcrum, as in fig. 8. The line from A to F is the long arm, B to F is the short arm. W is the weight, and P is the power. The object required by this lever is to lift the weight W by raising the extremity of the lever at A. In this, as in the case of the first kind of lever, the power is increased in proportion to its distance from the fulcrum.

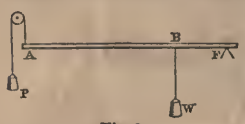

Fig. 8.

35. Examples of this kind of lever-power are common. One of the most familiar is that of a man pushing or lifting forward a bale of goods, as represented in fig. 9, in which the bale or weight W presses against the lever between the power P and the fulcrum F.

Fig. 9.

36. Another example of the second kind of lever is that of a man using a wheelbarrow, as represented in fig. 10. A point in the wheel of the barrow where it presses on the ground is the fulcrum. The body of the barrow, with its load, is the weight. And the two handles, lifted or held up by the man, form the power. In proportion as the man shortens or lengthens the handles in holding them, so does he increase or diminish the weight he has to sustain; increasing, however, by another law, the difficulty of pushing forward the barrow.

Fig. 10.

37. Two men carrying a load between them on a pole is also an example of the second kind of lever. The load may either rest upon or be dependent from the pole. In the case of two porters carrying a sedan chair by means of two poles, the load or weight is partly above and partly below the line of the lever. In the case of porters carrying a barrel slung from a pole, as in fig. 11, the weight is altogether below the lever. In both instances the principle is the same. Each man acts as the power in moving the weight, and at the same time each man becomes a fulcrum in respect to the other. If

the weight hang fairly from the centre of the pole, each man will bear just a half of the burden; but if the weight be slipped along to be nearer one end of the lever than the other, then the man who bears the shorter end of the pole supports a greater load than the man who is at the long end. The weight increases precisely in proportion as it advances towards him. Sometimes, when a man and a boy are carrying a handbarrow between them, the man, in order to ease the weight as much as possible to the boy, holds by the arms of the barrow near to where they join the loaded part.

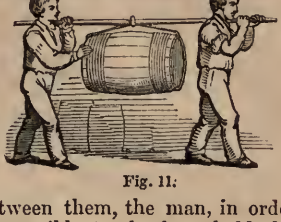

Fig. 11.

38. In yoking horses to the extremities of cross bars in ploughs, coaches, or other vehicles, care requires to be taken to hook the cross bar to the load at its centre, otherwise one horse will have to pull more than the other.

39. An inflexible beam resting on supports or fulcra at its two extremities, acts similarly as a lever of the second kind. Should no weight be appended to its centre, the weight of the material itself, when the extension is considerable, will be enough to bend it down, and even to break it. Extended flexible cords or chains are from this cause always bent down in the middle, no power of extension being able to overcome the gravity of the materials, which will give way before they can be rendered perfectly straight. The bended string of a boy's paper kite is an example of this powerful influence of gravity of materials.

40. The instrument used for cracking nuts (fig. 12) is an example of the second kind of lever with two arms or limbs. The fulcrum is the joint which connects the two limbs; the nut between them is the weight or resistance; and the hand which presses the limbs together, in order to break the nut, is the power. As each limb is a lever, a double lever action takes place in the operation.

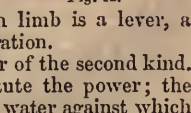

Fig. 12.

41. The oar of a boat in rowing is a lever of the second kind. The hands of the sailor who pulls constitute the power; the boat is the weight to be moved; and the water against which the blade of the oar pushes is the fulcrum.

42. The second kind of lever is sometimes employed as an instrument of pressure. The point of the short arm is, for example, pushed into a crevice or hole in a wall; the ful-

crum is the object to be pressed, and at the extremity of the long arm a heavy weight is applied. In this rude but efficacious manner are cheeses pressed in some parts of the country.

THIRD KIND OF LEVER.

43. In the lever of the third kind, the power is placed between the weight and the fulcrum (fig. 13). The fulcrum is at the extremity of the short arm at F; the weight W is dependent from the extremity of the long arm at A; and P is the power.

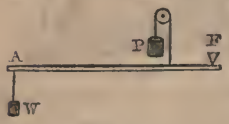

Fig. 13.

44. In this kind of lever, the power acts with considerable disadvantage, or with small effect; but this disadvantage is compensated by an opposite advantage, which is frequently of great importance in the operations of both nature and art. The advantage consists in the velocity with which a power will cause the extreme point of the long arm of the lever to move over a great space. This lever, therefore, whether in nature or art, is used only when a great space has to be traversed quickly by the long arm; but in this case the power must always be greater than the weight.

45. An example of this kind of lever is found in the foot-board of the turning-lathe (fig. 14). The foot of the workman presses on the board or plank near the end which rests on the ground, or fulcrum, and causes the opposite extremity of the board to move in a downward direction over a considerable space. A spring overhead, or a crank, pulls the board up again by means of a string S; the workman again presses it downward, and so a constant action of the string or cord which works the lathe is easily produced.

Fig. 14.

46. A man wielding a flail with two hands, and similar instances of using weapons, are also examples of the third kind of lever action. A similar action is observable when we use fire-tongs; a small motion of the fingers near the joint of the instrument causes the legs, which are two levers, to open or shut over a considerable space.

47. Before the peculiar advantages of this kind of lever became known, or were appreciated, it was called the *losing lever*.

48. The movements in the limbs of animals are generally produced by the action of this kind of lever power.

COMPOUND LEVERS.

49. When several levers of the simple kinds are connected together, and are made to operate one upon the other, the machine so formed is called a Compound Lever. In this machine, as each lever acts with a power equal to the pressure on it of the next lever between it and the power, the force is increased or diminished according to the number or kind of levers employed.

50. Fig. 15 represents a compound lever, consisting of three

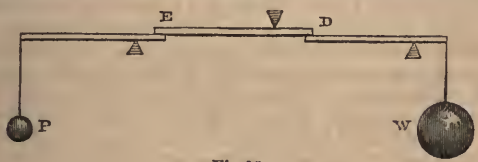

Fig. 15.

simple levers of the first kind, placed in a line, and each working on its own fulcrum. The desired object of the machine is for a small force or power at P, to move or balance a large weight at W. The same rule applies, in calculating the action of this combined lever, which has already been given for the simple lever—namely, "multiply the weight on any lever by its distance from the fulcrum; then multiply the power by its distance from the same point, and *if* the products are equal, the weight and the power will balance each other." Or, for the form of lever in the figure, "multiply the length of the long arm by the moving power, and multiply that of the short one by the weight or resistance."

51. It is supposed that the three levers in the figure are of the same length, the long arms being six inches each, and the short ones two inches each; required—the weight which a moving power of 1 pound at P will balance at W. In the first place, 1 pound at P would balance 3 pounds at E; we say 3, because the long arm being 6 inches, and the power 1 pound, 6 multiplied by 1 is 6; and the short one being 2 inches, we find that there are 3 twos in 6, therefore 3 is the weight. The long arm of the second lever being also 6 inches, and moved with a power of 3 pounds, multiply the 3 by 6, which gives 18; and multiply the short arm, being 2 inches, by a number which will give 18; we find that 9 will do so (9 twos are 18);

therefore 9 is the weight borne at the extremity of the short arm of the second lever at D. The long arm of the third lever being also 6 inches, and moved with a power of 9 pounds, multiply the 9 by 6, and we have 54; and multiply the short arm, being 2 inches, by a number which will give 54; we find that 27 will do so (twice 27 is 54); therefore 27 is the weight borne at the extremity of the short arm of the third lever. Thus 1 pound at P will balance 27 pounds at W: or 1 ounce at P will balance 27 ounces at W—the proportions being always alike, whatever denomination of weight we employ.

52. In this instance the increase of power is comparatively small, because the proportion between the long and short arms is only as 2 to 6, or 1 to 3. If we make the proportions more dissimilar, as 1 to 10, or 1 to 20, the increase of force becomes very great. For example, let the long arms be 18 inches each, and the short ones 1 inch each, and 1 pound at P will balance 18 pounds at A, and the second lever would be pushed up with a power of 18 pounds. This 18 being multiplied by the length of the lever 18, gives 324 pounds as the power which would press down the third lever. Lastly, multiply this 324 by the length of the lever 18, and the product is 5832 pounds, which would be the final weight at W which 1 pound at P would raise.

53. The following is a general rule for calculating the advantages of a compound lever consisting of any number of levers, whether equal or not:—Call the arms of the different levers next the power the *arms of power*, and the other arms the *arms of weight;* then, if the lengths of the arms of power and the power itself be successively multiplied together, the product will be equal to the continued product of the arms of weight and the weight, when the power and weight are in equilibrium.

54. A similar result to that of a combination of levers might be produced by only one lever, provided it were long enough; but the operation would be both clumsy and inconvenient. By combining levers, and making them act one upon another, great weights may be balanced within a small compass, and with an exceedingly small power. On this account machines are constructed with combinations of levers, for weighing loaded carts and other heavy burdens. The cart is wheeled upon a sort of table placed level with the ground, beneath which the levers are arranged; and a small weight placed on a scale attached to the extreme point of the first lever balances the load, which rests on the table above the last lever. This species of weighing-machine is often to be seen at toll-bars.

BENT LEVERS.

55. In the foregoing examples of lever powers, the levers or bars are supposed to be straight, and the powers and weights, or forces, are supposed to act at right angles with them.

56. Levers are frequently *bent* in their form, for purposes of convenience, and the powers and weights often act *obliquely*, or not at right angles.

57. In calculating the mechanical advantage of bent levers, the chief matter for consideration is *obliquity* in the direction of the applied power and weight. Obliquity in the action of the forces generally diminishes the mechanical advantage.

58. Whatever be the form of the lever, or the direction of the power and the weight, the mechanical advantage of the power or the weight is always represented by *a line drawn from the fulcrum, at right angles to the direction in which the forces are respectively exerted.*

59. Fig. 16 is a bent lever, with the power P hanging from A, and the weight W hanging from B. In this case, both the power and the weight act at right angles to an ideal line, drawn as from E to G across the fulcrum, which strikes the lines of direction of the forces at right angles. This ideal line therefore represents the true lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25). In this manner the bending goes for nothing.

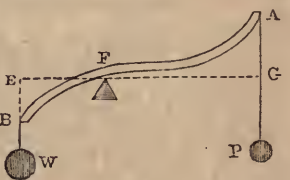

Fig. 16.

60. Fig. 17 is a straight lever with the power P acting obliquely from D to A, and the weight W acting obliquely from G to B. In order to calculate the power of this kind of lever, we must draw lines as represented in fig. 18. First, we draw a line obliquely upwards in the direction of the pulling power. This line is seen dotted from A to M. We then draw a line off from it, or *at right angles* with it, to F, the fulcrum. This line is seen dotted and marked H. We next draw a line obliquely upwards in the direction of the pull of the weight, as from B

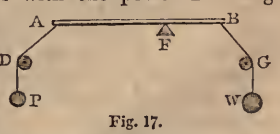

Fig. 17.

to N; and in the same manner as before draw a line *at right angles* from it. This line is seen dotted and marked K. We have now found an ideal lever, with two arms, H and K. This ideal lever is the true lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25).

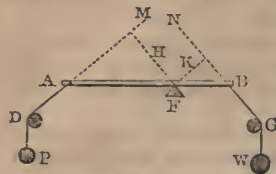

Fig. 18.

61. The next example, fig. 19, represents the power and weight acting obliquely the same as in fig. 18; but in this case the lever is bent. The bending of the lever, however, does not affect the rule of calculation, which is the same as in fig. 18. We begin by drawing a line obliquely upwards in the direction of the pulling power. This line is seen dotted from A to C. We then draw a line off from it, or at *right angles* with it, to F, the fulcrum. This line is seen dotted from C to F. We next draw a line obliquely upwards, in the direction of the pull of the weight; and in the same manner as before draw a line at *right angles* from it (as from D) to F. We have now found an ideal lever; from C to F being the long arm, and F to D the short arm. This ideal lever is the lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25).

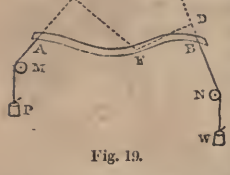

Fig. 19.

62. Sometimes the lever is bent in such a manner that the long arm rises perpendicularly from the fulcrum, as in fig. 20. In this case the upright long arm from F to A acts precisely as if it were horizontal, because the power or hand is supposed to act at right angles to the arm. If we were to draw an ideal line from the top of the arm at A directly downwards to F, it would descend straight through the arm, and hence in this case there would be no use in drawing it. The calculation may be made with the arm itself.

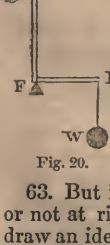

Fig. 20.

63. But if the power be made to draw obliquely downward, or not at right angles to the line from the fulcrum, we must draw an ideal line, as represented in fig. 21. The line of direction of the power is seen proceeding obliquely from A to the hand P. A dotted line H is drawn at right angles from this

line to F, the fulcrum; the line H therefore represents the true arm of power of the lever.

64. Suppose the line of direction of the power in the last figure had been drawn slantingly upward instead of downward, then an ideal dotted line would have been to be drawn obliquely downward from it, crossing the arm at A, and a line drawn at right angles from it to F would have represented the true arm of power.

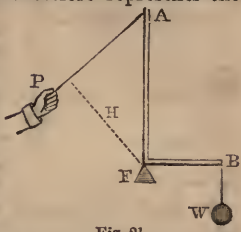

Fig. 21.

65. The adjoining figure (22), representing a pronged hammer in the act of being employed to extract a nail, is an example of a bent lever, resembling those just mentioned. The hand of the workman is the power exerted on the long arm of the lever; the head of the hammer, where it presses on the flat surface beneath it, is the fulcrum; the prongs are the short arm of the lever, and the resistance of the nail is the weight.

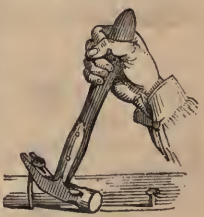
Fig. 22.

66. From the examples now given, it will be observed that, whatever be the shape or bending of the lever, and whatever the degree of obliquity of the applied force, the power of the machine may be calculated by drawing ideal lines at right angles from the lines of the forces to the fulcrum, and making the calculations from them.

RECAPITULATION OF LEVER POWERS.

67. To avoid confusion or misapprehension, representations of the three kinds of levers already defined are here again exhibited, along with a few brief explanatory observations on their character and comparative value. For the sake of clearness, a hand pulling is substituted as the power. The *arm of the power* is used to signify the long arm, and the *arm of the weight* the short arm.

68. Each of the three kinds of levers has its own special advantages, and is peculiarly adapted to certain situations and

purposes. In a lever of the first kind (fig. 23), where the point of support is between the power and the weight, either the power or the weight may have the advantage. The advantage varying thus between the power and the weight, the lever of the first kind is held to be most convenient for an equilibrium; of which, as has been already shown, the common weighing balance affords an example.

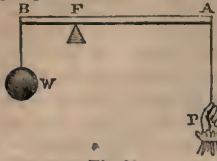

Fig. 23.

69. In the lever of the second kind (fig. 24), the arm of the power is necessarily longer than that of the weight or resistance, since the resistance is between the power and the fulcrum, whilst the power is at one extremity. The advantage being thus always in favour of the power, the lever of the second description is always favourable for overcoming resistance.

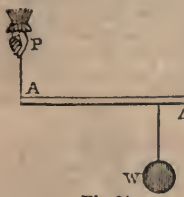

Fig. 24.

70. In the lever of the third kind (fig. 25), on the contrary, the advantage is in favour of the weight or resistance, which is placed at an extremity, while the power lies between it and the point of support. But the disadvantageous position of the power in this kind of lever is compensated by the extent of motion which necessarily ensues from that very disadvantage; for the closer the power is to the fulcrum, and the farther it is from the weight, the more extensive and rapid is the motion to which the weight can be subjected on the slightest action of the power. The lever of the third kind, therefore, is obviously favourable to extensive and rapid movements.

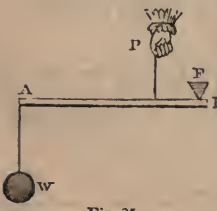

Fig. 25.

ANIMAL LEVERS.

71. A short consideration of the characteristic advantages and defects attendant on each of the three kinds of levers, will suffice to convince us of the superior applicability of the third kind of lever to the purposes of animal motion. Celerity and extent of motion, it is obvious, are here objects of paramount importance; and by the employment chiefly of this species of lever, both in the trunk and the limbs, they are beautifully and

effectually attained. In the animal machine, the bones form the *arms* of the levers; the muscles, contractible at the command of the will or fancy, represent the *power;* the joints, the *fulcrums* or points of support; and the weight of the body, or of individual limbs, as it may happen, constitutes the *weight* or resistance, increased, as in the case of the hands at times, by some substance carried or held by them. The most important result of the lever powers of the animal machine is locomotion, or the transmission of the whole body from place to place.

72. The spinal or vertebral column, when we regard its motions as a whole, represents a lever of the third kind, of which the fulcrum is in the articulation of the last bone of the column with the *sacrum* (the bone on which the trunk rests); the power being in the muscles, which are inserted into the vertebral column along its course, and the resistance in the weight of the head, neck, and trunk.

73. But a much more distinct and intelligible example of a lever of the third kind in the animal frame is exhibited in the human arm. A strong muscle, arising in the shoulder, passes down in front over the joint of the elbow, and is inserted into one of the two parallel bones which compose the framework of the forearm, or from the elbow to the wrist. On being contracted in the slightest degree, at the impulse of the will, this muscle (the *power*) elevates instantaneously the hand (the *weight* or resistance) to the shoulder, bending the arm upon the elbow-joint (the *fulcrum*). Fig. 26 illustrates perfectly this mechanism of the arm. F represents the elbow-joint, P the power or will acting over, or from, the shoulder S, through the contracting muscle M, and B the arm from the hand to the elbow, while the weight W is an object supposed to be placed in the hand.

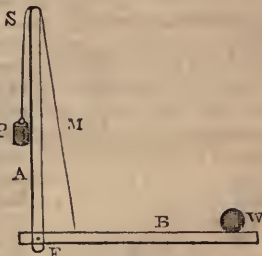

Fig. 26.

74. Nothing can better illustrate the characteristic advantages of levers of the third kind than this action in the human arm. The contraction of the muscle, to the extent of only one inch, raises the hand, even with a very considerable weight in it, through a semicircle of twenty-one inches; and by relaxing the muscle only a little, the hand, as represented in fig. 27, is allowed to drop over a similarly wide range. No doubt other muscles in the arm assist in this action, but the principal

part is performed by the one described, and here indicated by the letter M.

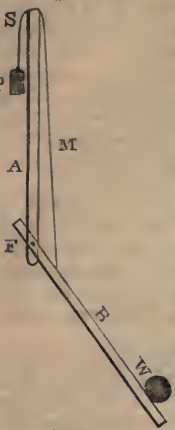

Fig. 27.

75. It is worthy of observation, that in the second of these figures, illustrating the mechanism of the arm, the lever power acts under increased disadvantage, from the greater inclination of the limb than in the preceding figure. We can raise or sustain a much larger weight with the hand when the arm is bent at right angles, than when it is extended nearly in a straight line; and the more the arm is stretched out, the more is the power diminished. What is gained, however, in force, is necessarily lost in extent of motion.

76. A fine example in the animal frame of the lever of the third kind, where extent of motion was not the object wanted, as it is in the arm, is seen in the mechanism of the lower jaw. To overcome resistance was in this case the chief end required; and accordingly we find a strong muscle, constituting the power, passing perpendicularly downwards from the side of the head to the lower jaw-bone, and acting on it in a straight line, the fulcrum being in the articulation of the jaw near the ear. The force with which the power acts in this case is immense, particularly when the resistance to be overcome is placed near the fulcrum, or directly beneath the action of the muscle. We take advantage of this circumstance in cracking nuts, for example, by putting them to a certain distance back between the jaws.

77. As in the arms, so also in the inferior extremities, the principal muscles hold such a relative position to the bones and joints, as to sustain the weight of the body, and transfer it along the surface of the ground, with all the advantage of a lever power of the third kind. If the mechanical action of the muscles and bones in animals, whether in the spinal column or in the limbs, had been arranged on the principle of either of the other descriptions of levers, the requisite contraction in the length of the acting muscles would have been so great, as to render the shape of the limbs, and indeed the whole figure, extremely clumsy, and the movements very inconvenient; and hence the wisdom of the existing arrangement in regard to simplicity, beauty, and efficiency.

78. Examples of the first and second kinds of levers are not

absent in the animal machine; and where such examples occur, they uniformly corroborate what has been said respecting the peculiar character of each of the three kinds of levers. The head, for instance, requires, for the fulfilment of its exalted uses, and for the comfort of the being, to be maintained erect, and in equilibrium. A lever of the first kind, we have seen, is the one best calculated to effect this object, and accordingly such a mechanism is found to exist here. The point of support of this lever is in the articulation of the lateral masses of the two first bones of the spinal column, whilst the power, and the resistance or weight, occupy each an extremity of the lever, represented, the one by the face, and the other by the back part of the head. To understand this fully, it must be explained that the point of support, or *fulcrum*, on which the head rests, is much nearer to the back part of the skull than to the fore part or face; therefore this fore part (the *weight* of the lever) has a tendency to fall forwards, but is retained in equilibrium by the strong muscles passing from the lower parts of the neck to the hind part of the head (which is thus rendered the site of the power of the lever). A perfect lever of the first kind is thus made the agent in maintaining the head in equilibrium.

79. In like manner it might be shown that where there is a considerable resistance to be overcome, the bones and muscles are so arranged as to represent a lever of the kind best calculated for the fulfilment of such a purpose—namely, a lever of the second kind; as the first is employed when an equilibrium is to be maintained, and the second when rapid and extensive motion is to be produced.

THE WHEEL AND AXLE.

DEFINITIONS.

80. A lever has been defined (10) to be "a rod or bar of iron, wood, or any other material which is movable upon or about a prop or fulcrum, or about a fixed axis."

81. The illustrations which have been given show the lever only in its character of a simple bar, which is movable in some part "upon or about a prop or fulcrum." It is now to be shown how it acts when movable upon or about a fixed axis.

82. When a lever is movable upon an axis, and is susceptible of being turned completely round, it assumes the character of the diameter of a wheel.

83. In fig. 28, the simple rudiments of a wheel are represented. A and B are the two arms of a bar or lever playing upon a fixed axis at F, and which axis is the fulcrum. If we push down A, we raise B; or if we push down B, we raise A. In this manner the situation of the power and the weight is transferable from one end to the other, as in the beam of a common balance, without altering the equilibrium.

Fig. 28.

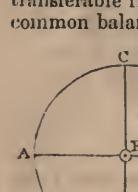

Fig. 29.

84. Fig. 29 is a representation of a wheel in a state more advanced to completion. Here the arms A B are connected with the arms D C, both at the centre F, and by means of the circumference or rim of the wheel. By reason of this union of parts, the central axis at F becomes the common fulcrum for every portion of the wheel; therefore from the centre to any point of the circumference is an arm of a lever, although the line of that lever be not marked or seen, as in the case of a distinct spoke.

85. A line through the centre from one side of the circumference of a wheel to the opposite side, is the diameter; from the centre to any part of the circumference, is the semi-diameter or radius. The arms or spokes are said to radiate from a centre. The circumference is sometimes called the periphery.

86. Besides wheels with axes in the centre, there are wheels with axes not in the centre, called eccentric wheels. At present, however, we are treating only of wheels having their axes in the centre.

87. Wheels with a central axis may be rendered available as levers in various ways, according to the placing of the weight or resistance. The plan commonly pursued consists in giving to the wheel an axle, which is fixed to its arms, and placing a weight near the axle or fulcrum, to work against another weight at the circumference.

88. Thus a machine is formed called the Wheel and Axle, which constitutes one of the simple mechanical powers, founded on the lever.

PRACTICAL APPLICATIONS.

89. The machine termed the Wheel and Axle consists of a wheel fixed upon an axle or spindle, which axle turns on its two ends in upright supports. See fig. 30. The fulcrum of the machine is common to both the wheel and the axle, and is

the centre of the axle. A is the wheel, B is the axle, and H is a handle with which the machine may be turned. By turning the wheel, the axle is also turned, and a rope being fixed to the axle, with the weight W hanging at its extremity, the turning of the wheel causes the axle to wind up the rope, and so lift the weight. If, instead of turning the wheel with the hand, we wind a rope round the circumference of the wheel in a contrary direction from that in which the axle-rope is wound, and also hang a weight of a certain heaviness, P, to its extremity, then the draught or pulling of the wheel-rope in unwinding will turn the axle, and so wind up the axle-rope with its weight. In this manner one power works against another, exactly as in the case of the lever. By properly apportioning the two powers in correspondence with the diameters of the wheel and the axle, the one power or weight may be made to balance the other power or weight, so as to produce an equilibrium of the machine.

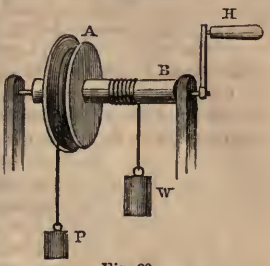

Fig. 30.

90. The wheel and axle form what is called a PERPETUAL LEVER. Common simple levers act only for a short space, or by reiterated efforts, so as to be adapted for lifting an object from one place to another on the ground. The perpetual lever, formed by the wheel and axle, turns round without intermission, and is therefore suitable for lifting weights attached to a rope, through a considerable space upward from the ground without stopping.

91. Fig. 31 is a representation of the machine endwise, and shows how the lever operates. The line going across the machine from A to B represents the line of the lever. A is the situation of the power, F is the centre or fulcrum, and B is the situation of the weight; therefore from A to F is the long arm, and from F to B is the short arm of the lever. In other words, the long arm is half the diameter of the wheel, and the short arm is half the diameter or thickness of the axle.

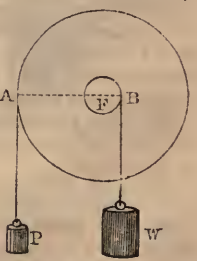

Fig. 31.

92. By widening the wheel, and so lengthening the long arm of the lever, the smaller will be the power necessary to overcome the

weight on the axle or short arm; but what is gained by this mechanical advantage is lost by the circumstance, that the power must descend through a proportionally greater space in order to raise the same weight through the same space in the same time. This is in agreement with the principle mentioned in paragraph 17.

93. To find what forces will balance each other, let the same rules be followed as those given for the simple lever in paragraph 25. Multiply the weight by its distance from the fulcrum (that distance is half the diameter of the axle); then multiply the power by its distance from the same point (that is, half the diameter of the wheel), and if the products be equal, the weight and the power will balance each other. Thus a power of one pound at or depending from the circumference of a wheel of twelve inches in diameter, will balance a weight of twelve pounds at or depending from the circumference of an axle one inch in diameter.

Note.—No allowance is made in these calculations for the overlaying of the rope in winding, which affects the length of both the long and short arm; but this is a matter of practical, not of theoretic import.

94. The principle of the wheel and axle, or perpetual lever, is introduced into various mechanical contrivances, which are of great use in many of the ordinary occupations of life. One of the simplest machines constructed on this principle is the common windlass for drawing water by a rope and bucket from wells. Coal is lifted from the pits in which it is dug by a similar contrivance, wrought by horse or steam power.

95. The capstan in general use on board of ships for hauling or drawing up anchors, and for other operations, is an example of the wheel and axle, constructed in an upright or vertical, instead of a horizontal position. In fig. 32, one of these capstans is represented. The axle is placed upright, with the rope winding about it, and having a head pierced with holes for spokes or levers, which the men push against to cause the axle to turn. This is a powerful and convenient machine on shipboard; when not in use, the spokes are taken out and laid aside.

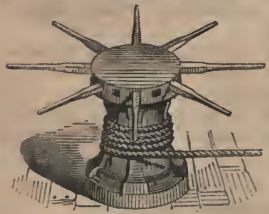

Fig. 32.

PULLEYS.

96. The pulley and cord is one of the primary mechanical powers. A pulley is a wheel with a groove in its circumference, and suspended by a central axis. In fixed pulleys, a flexible cord, which is made to pass over and hang from the upper part of the groove, has at one extremity a certain weight to be raised, and at the other extremity a power is attached for the purpose of pulling. There are two kinds of pulleys—the *fixed* and *movable*.

FIXED PULLEYS.

97. The annexed cut, fig. 33, represents a fixed pulley. A is the wheel; B is a beam or roof from which the wheel is suspended. P is the power hanging at one end of the rope, and W is the weight at the other end. This kind of pulley is called a fixed pulley, because it does not shift from its position.

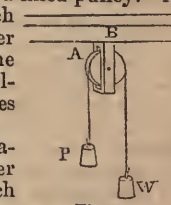

Fig. 33.

98. The fixed pulley possesses no mechanical advantage. The wheel is merely a lever with equal arms, and therefore the cord which passes over these arms gains no advantage. To raise a pound weight from the ground at the one end of the cord, the power of one pound must be exerted at the other.

99. The object of the single fixed pulley is not to save power, but to give convenience in pulling. For instance, by pulling downwards, a weight may be raised upwards, or by pulling in one direction, a load may be made to proceed in another. The same object might be gained by drawing a cord over a fixed post or pivot; but in this case the friction of the cord would chafe or injure it; the wheel or pulley is therefore a simple contrivance to prevent friction, for it turns round along with the cord.

MOVABLE PULLEYS.

100. The movable pulley is in form the same as the fixed pulley, but instead of being placed in a fixed position from a beam or roof, it hangs in the cord which passes under it, and from its centre or axis the weight is suspended. In fig. 34, a movable pulley is represented. A is a hook in a beam, to which one end of a cord is fixed. B is the movable pulley,

under which the cord passes, and proceeds upwards to C, a fixed pulley, from which it depends to P, the power or the hand pulling. The fixed pulley C is of no further use than to change the direction of the power. W is the weight hanging from B.

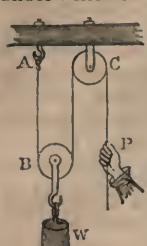

Fig. 34.

101. The movable pulley possesses a mechanical advantage. The first point to be observed is, that the weight hangs in the cord; second, that the weight presses down each side of the cord equally—that is, it draws as hard at A as at C or P; third, that the consequence of this equal pressure is the halving of the weight between the two ends of the cord, so that the end held in the hand sustains only half the pressure of W. The HALVING OF THE WEIGHT is therefore the mechanical advantage given by the movable pulley.

102. EXAMPLE.—If the weight W be ten pounds, five pounds is borne by A, and five pounds by P. The case is precisely the same as that of two boys carrying a basket between them. The basket is the weight, and each boy, with his hand upholding the handle, bears only half the load, whatever it may be. If, instead of holding by the handle, the boys slip a cord beneath it, and each take an end of the cord, the case is the same.

103. In order to save expenditure of power in lifting weights by pulleys, it is always contrived to cause some inanimate object—as, for instance, a beam or roof—to take a share of the weight, leaving only a portion to be borne by the person who pulls. But in this, as in all cases of mechanical advantage, the saving of power is effected only by a certain loss of time, or a longer continuation of labour. To lift a weight one foot from the ground by the movable pulley, a man must pull up the cord two feet; therefore, to lift a weight, it will take double the exertion to draw it up a given height without the pulley, that it would require with the intervention of the pulley.

Fig. 35.

104. As the power which a man can exert by his hands is able to overcome a weight greater than the weight of his own person, this circumstance may be taken advantage of in a very peculiar manner through the agency of the fixed pulley. As represented in fig. 35, a man may seat himself in a loop

or seat attached to one end of a cord, and passing the cord over a fixed pulley above, may pull himself upwards by drawing at the other end of the cord. By adding a movable pulley and another fixed pulley to the apparatus, the exertion of pulling would be diminished one half. An apparatus of this nature, having two fixed pulleys, and one movable pulley, is used by house masons and other artisans in making repairs on the fronts of buildings.

PRINCIPLE OF THE PULLEY POWER.

105. The principle upon which pulleys act, is the distribution of weight throughout the different portions of the cord, so as to lessen the power necessary to be exerted by the operator. And along with this principle is the changing of the direction of the power for the sake of convenience in pulling.

106. According to ordinary language, the mechanical power of which we are treating is called the power of the pulley; but, in reality, as has been just shown, the pulley has no power in itself. The power of the machine is in the cord. IT IS THE EQUAL TENSION OF THE CORD THROUGH ITS WHOLE LENGTH, BY WHICH THE WEIGHT IS DISTRIBUTED UPON INTERVENING POINTS, THAT THE MACHINE OFFERS ANY MECHANICAL ADVANTAGE.

107. In all cases in which cords are drawn tightly, so as to hold objects in close contact, the same species of power or mechanical advantage is exemplified. For instance, in drawing a cord in lacing, or a thread in sewing, this distribution of power is observable. If all the power which is distributed throughout the sewing of a single pair of strong shoes were released and concentrated in one main draught, it would in all likelihood be a power sufficient to lift one or two tons in weight.

108. Technically, the wheel of a pulley is called a *sheave;* for protection and convenience, this sheave is ordinarily fixed with pivots in a mass of wood called a *block;* and the ropes or cords are called a *tackle.* The whole machine fully mounted for working is termed a *block and tackle.* By causing a wheel and axle to wind up the cord of a block and tackle, the power of the lever is combined with that of the pulley in the operation.

109. There is no assignable limit to the power which may be exerted by means of pulleys. The machine may be constructed to raise with ease any weight which the strength of materials will bear, provided the combination is not so complex as to exhaust the power by the friction produced.

110. The power of pulleys is increased by a combination of wheels or sheaves in one tackle. There are different kinds of combinations or systems of pulleys. In some there is only one fixed pulley, and in others there are several.

COMBINATIONS OF PULLEYS.

The following are examples of different combinations of pulleys:—

Fig. 36.

111. Fig. 36 represents a compound system of pulleys, by which the weight is distributed through four folds of the same cord, so as to leave only a fourth of the weight, whatever it may be, to be raised by the operator. In this illustration, the cord number 1 bears one fourth of the weight; the cord number 2 bears a second fourth; the cord number 3 bears a third fourth; and the cord number 4 bears a fourth fourth. Here the mechanical advantage ceases. For although the cord number 4 passes over the topmost fixed pulley down to the hand of the operator, no more distribution of power takes place; this topmost pulley being of use only to change the direction of the power. The person who pulls has thus only a quarter of the weight to draw. If the weight be one hundred pounds, he has the labour of pulling only twenty-five pounds.

112. Thus it is observable that the diminution of weight is in proportion to the number of movable pulleys. To calculate the expenditure of power or diminution of weight, therefore, we have only to multiply the number of movable pulleys by two, and the product shows the power to be exerted. Two movable pulleys multiplied by two, gives four; therefore a fourth of the weight is the power required; and so on. The addition of a single movable pulley to any system of pulleys, at once lessens the apparent weight one half, or in other words, doubles the effect of the power; but every such addition causes more time to be spent in the operation, there being, at every additional fold of the cord, more cord to draw out, and also more friction to overcome.

113. In the annexed system of pulleys, fig. 37, a series of movable pulleys, with different cords, are made to act successively on one another, and the effect is doubled by each pulley. At the extremity of the first cord, a power of one pound depends. This cord, marked 1, by being drawn below a movable

pulley, supports 2 pounds; that is, 1 pound on each side. The next cord, marked 2, in the same manner supports 4 pounds, or 2 pounds on each side. The next cord, marked 4, supports 8 pounds, or 4 pounds on each side. Thus, 1 pound at P supports 8 pounds at W. If another movable pulley were added, the 1 pound at P would support 16 pounds; and so on.

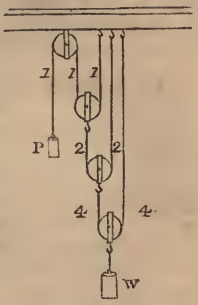

Fig. 37.

114. In working pulleys, the line of the power must be in the same plane with the line of the weight. If the power be applied obliquely, or if the rope draw sideways upon a pulley, there will be a loss of power.

PRACTICAL APPLICATION OF PULLEYS.

115. Pulleys are used chiefly on board of ships, where blocks and tackle are in constant requisition for raising and lowering the sails, masts, and yards. They are likewise in considerable use by house-builders and others, in connection with the wheel and axle, for raising or lowering heavy masses of stone and other articles.

116. Fig. 38 is a representation of a system of pulleys commonly used in practical operations. Three movable pulleys are enclosed in the block A, and three fixed pulleys are enclosed in the block B. Suppose, therefore, that the weight W, in this case, is six hundred pounds, the hand P pulls it upwards by exerting a force of only one hundred pounds. A combination of pulleys resembling this is used in turning kitchen jacks. The weight in sinking draws off the cord from a spindle, by which motion the jack is turned. In order that a considerable weight falling slowly through a comparatively small height may keep the jack in motion for a long time, as many as ten or twelve movable and fixed pulleys are used.

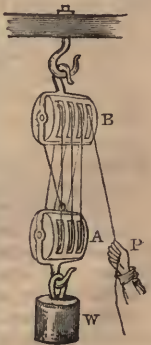

Fig. 38.

117. A horizontal plane is a plane coinciding with that of the horizon, or parallel to it, as shown by a water level; when the plane is not level or horizontal, but lies in a sloping direction, with one end higher than the other, it is said to incline, or is called an inclined plane. In fig. 39, A B is the *horizontal*, and A C the *inclined* plane.

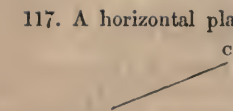

Fig. 39.

STANDARDS OF COMPARISON FOR INCLINATIONS.

118. The inclination of a plane may be to any extent, from that of a slight rise off the horizontal, to almost an upright or perpendicular ascent. For the sake of convenience in language, the extent of the inclination is defined by comparing it to the numbers of degrees in the quarter of a circle. A circle being divided by mathematicians into 360 degrees or parts, the quarter of the circle includes ninety degrees. Taking, then, a quarter of a circle, and marking it, as in fig. 40, H L is the horizontal line, and P L is the perpendicular line ascending from it. Any line drawn from the centre to any point on the circumference defines the degree of inclination. Thus a line ascending from the centre to the 10th degree is called an *inclination* or *angle of ten degrees;* a line ascending to the 45th degree is called an *inclination* or *angle of forty-five degrees;* and so on with all the other degrees, to the 90th, or perpendicular. In this manner a standard of comparison has been established for defining the various slopes or inclinations in planes.

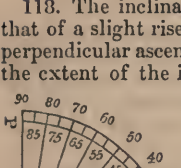

Fig. 40.

119. Another standard of comparison for slopes consists in referring the rise to so many feet in a certain length or distance—as, for instance, a rise of one foot in ten feet, a rise of one foot in twenty, a rise of so many inches in a mile; and so on.

120. In the case of inclinations of hills, or other elevations composed of loose matter, there is a certain degree of sloping, which will permit the materials to remain at rest, and not slide or roll down in obedience to the law of gravitation. The degree of inclination at which the particles of matter remain

at rest, just before they would slide down, is termed the *angle of repose*. This angle is of course different in different kinds of bodies.

PRINCIPLE OF THE POWER OF INCLINED PLANES.

121. The inclined plane, as already stated, is a primary mechanical power. The object which is accomplished by it is the raising of weights to considerable elevations, or the overcoming of resistances by the application of lesser weights and resistances; or making a small power overcome a greater.

122. To raise a load of a hundred pounds to an elevation of fifty feet by a direct perpendicular ascent, and without using any mechanical advantage, the power exerted must be a hundred pounds, or equal to the weights to be overcome. If, instead of raising the load directly upwards, we raise it by the gradual ascent of an inclined plane, the power required is less than a hundred pounds, and the diminution is in proportion to the smallness of rise in the inclined plane. But this saving of power, as in all other instances of mechanical advantage, is accomplished only by a corresponding loss of time.

123. In drawing a load, as, for instance, a loaded carriage, along a horizontal plane, the resistance to be overcome is chiefly the friction of the load upon the plane. If there were no friction or impediment from inequalities of surface, and no other resistance, and if the load were once put in motion, it would go on moving with the smallest possible expenditure of power.

124. In drawing a load up an inclined plane, ordinary friction has to be overcome, and also the gravity of the body, which gravity gives it a tendency to roll down to the lowest level. In this constant impulse to descend, it is not at liberty to pursue the same line of descent as bodies falling freely from heights. It falls or rolls down as much less speedily than a free falling body (omitting the loss by friction) as the length of the inclined plane is greater than its height. A freely-descending body falls about 16 feet in the first second; and a body rolling down an inclined plane, rolls just as many feet the first second as the number of feet of inclination is in sixteen feet. If the inclination be one foot in sixteen, the body rolls down one foot; and so on.

125. Any body, in being drawn up an inclined plane by a power parallel with the plane, presses at right angles with the plane. The common expression is, that the reaction of the plane upon the object is perpendicular to the plane. When an object, as a ball, rests upon a horizontal plane, its pressure is at right angles with the plane; or, what is the same thing,

the reaction or resistance of the plane is at right angles with it. This is seen in fig. 41, in which a ball is represented lying on a level plane, with the line of pressure A passing down to B, which line is at right angles with the plane. Suppose, then, that the end of the plane at C is elevated to D, as in fig. 42, so as to form a slope; in this case the line of pressure of the ball on the plane is also moved, so as still to be at right angles with the inclination.*

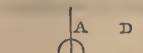

Fig. 41.

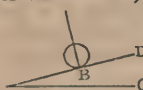

Fig. 42.

126. The power which is required to be sustained for the purpose of overcoming friction or inequalities of surface on level planes, is for the purpose of drawing the load up or over the inequalities.

RULES FOR CALCULATING THE POWER OF INCLINED PLANES.

127. The amount of the power corresponding to different weights and inclinations of the plane has been correctly ascertained; and the following are the rules upon the subject:—

128. *First.*—The quantity of weight is great in proportion to the inclination of the plane; consequently, so is the difficulty of raising greater.

129. *Second.*—To overcome the weight or resistance, and the slowness of movement, a corresponding increase of power must be given.

130. *Third.*—The smaller the inclination, so is the pressure of the weight on the plane the greater, and the power required to move it up smaller.

131. *Fourth*, or special rule of calculation.—Whatever is the unit of inclination in a given length, the same is the unit of weight that can be lifted, and the unit of power to be exerted.

EXAMPLES.

132. If the inclination of a road be *one* foot in ten, *one-tenth* is called the unit of inclination; hence, *one-tenth* part of the nominal weight of the load has to be lifted; and a power to draw this one-tenth part of the load has to be exerted; or, to put the case in other words, if the road rise one foot in ten, there is in the ten only one foot of perpendicular height to be lifted through; and the weight at any point of the ten feet is

* This proposition is proved by a mathematical demonstration which it is thought inadvisable to introduce here. The question is one of Resolution of Forces, and is treated of in works for advanced students.

only a tenth of what it would be if it were to be lifted through a perfect perpendicular ascent of ten feet. This is exemplified

Fig. 43.

in fig. 43, in which a loaded cart is in the act of being drawn up an inclined plane of ten feet in length, having a rise of one foot throughout its extent—that is, from A to B. This rise of one foot is marked at the end of the plane, from C to B. Although, therefore, the cart has to be pulled a distance of ten feet, it in reality is pulled *upwards* only one foot, and the horse which draws has the advantage of pulling only one-tenth.

133. The reason is now perceived why a small power overcomes a greater in the case of draughts upon inclined planes. The load is, as it were, lifted by instalments. Partly supported as it advances, and always supported more completely the smaller the inclination, the weight of the burden is apparently lessened by merely taking the rise gradually and slowly.

134. If we suppose a case of two roads, the first rising one foot in twenty, and the second rising one foot in fifty, a loaded carriage will be found to go over the fifty feet of the one with precisely the same expenditure of power that would be required to make it go over the twenty feet of the other—that is, always providing that friction and other circumstances are alike.

135. Fig. 44 represents a supposed case of two inclined planes of the same height, but different slopes, meeting together at the top, with a weight resting on each, P and Q, hanging by a string, which passes over the pulley M. If the length of the longest plane from A to M be two feet, and that of the shorter from B to M be one foot,

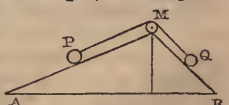

Fig. 44.

then two pounds at Q, on the short side, will balance four pounds at P, on the long side; and so on in this proportion, whether the planes be longer or shorter.

136. In this manner, weights moving on two adjoining inclined planes may be adjusted so as to balance each other, although the inclinations be different; and they are so made to act on various sloping railways connected with public works,

where one wagon descending on one plane is made to draw up another wagon on another plane.

137. An inattention on the part of our forefathers to these exceedingly simple principles of mechanical science, led them to form roads over steep hills, pursuing, as it was imagined, the best routes, because they were the straightest in a forward direction. In modern times, this error has been avoided by enlightened engineers, and roads are now constructed with as few risings and fallings as possible. When roads have necessarily to be carried to the summits of heights, they are very properly made either to wind round the ascent, or to describe

Fig. 45.

a ziz-zag line of direction. Fig. 45 represents a road constructed in a winding direction round a hill on which a fort is planted, and which it would otherwise be impossible to ascend.

138. The drivers of carts are aware of the saving of labour to their horses by causing them to wind or zig-zag up steep roads, instead of leading them directly forward.

139. The inclined plane is resorted to for a saving of labour in many of the ordinary occupations of life. By it, loaded wheelbarrows are with comparative ease wheeled to considerable elevations in house building and other works of art; hogsheads are rolled out of or into wagons, and ships are launched into or drawn from the water, the inclined plane being as useful in giving facilities for letting down loads as in drawing them up.

140. It is also by inclined planes that we reach the higher floors of a house from the ground, or attain other elevations. For all such purposes, the inclined plane is formed with steps

to insure our safe footing. All stairs or flights of steps are inclined planes.

THE WEDGE.

141. The inclined plane has been described as being fixed or stationary—as, for instance, a common ascending road, or a sloping plank, upon which the weights are moved. It has now to be viewed as a *movable plane*, in which form it suits many useful purposes.

142. When an inclined plane is movable, and the load or weight which it affects is at rest, it receives the name of a Wedge. The wedge is therefore a mechanical power, founded on the principle of the inclined plane.

Fig. 46.

143. The wedge is an instrument or simple machine, consisting of a solid body of wood, iron, or some other hard material, and is triangular in form. See fig. 46. Here the wedge is seen to taper from a thick end or head at B to a thin edge or point at A. This, however, is only the more common form of the wedge. It is made with sides of various angularities or degrees of slope; and in some cases it possesses a flat and a sloping side, as in fig. 47. When it slopes on both sides, it consists of two inclined planes joined together, and when one of its sides is flat, as in fig. 47, it acts as only one inclined plane.

Fig. 47.

144. The wedge is employed as an instrument for cleaving solid masses asunder, to compress bodies more closely together, and to move great weights through small spaces. Fig. 48 is a front view of a wedge in the act of splitting asunder a piece of timber. The power employed to force the wedge forward, is either repeated blows with a mallet or hammer, or the gradual pressure of a weight. In general, the power is applied by rapid strokes, or quick applications of some kind of external pressure.

Fig. 48.

RULES FOR CALCULATING THE POWERS OF THE WEDGE.

145. The rules for calculating the power of the wedge are similar to those for the inclined plane. In proportion as the inclination or angularity is great, so is the resistance greater, and the power must be greater to overcome it. Thus, if the wedge

be of short dimensions, and thick at its head, it will require a greater power to move it than if it be long, and thin in its form.

Fig. 49.

146. The resistance offered to the wedge of equal sides, when the pressure is equally applied, is, as in the case of the inclined plane, at right angles with the sides. See fig. 49, in which the oblique cross lines represent the direction of the pressure passing at right angles through the sides, and meeting at the centre.

147. It is difficult to calculate the precise power of the wedge, for much depends on the force or the number of blows which may be given it, together with the obliquity of the sides, and the power of resistance in the object to be split. In the splitting of timber, for instance, the divided parts act as levers, and assist in opening a passage for the wedge.

EXAMPLES OF WEDGE POWERS.

148. The wedge is the least used of the simple machines, but the principle upon which it acts is in extensive application. Needles, awls, bodkins, and driving-nails, are the most common examples. Knives, swords, razors, the axe, chisel, and other cutting instruments, also act on the principle of the wedge; so likewise does the saw, the teeth of which are small wedges, and act by being drawn along while pressed against the object operated upon.

149. The principle of the inclined plane, which is the basis of that of the wedge, is particularly observable in the action of the razor and the scythe, both of which cut best by being drawn along the materials against which they are applied. When the edge of a scythe or razor is examined with a microscope, it is seen to be a series of small sharp angularities of the nature of the teeth of a saw.

Fig. 50.

150. The principle of the wedge operates in the case of two glass tumblers, one placed within the other, as in fig. 50. A very gentle pressure applied to the uppermost tumbler would be sufficient to burst the lower. At every little advance of the uppermost tumbler, it acts more and more as a lever power on the rim of the lower, and at last overcomes the resistance, and fractures the vessel.

THE SCREW.

151. The screw is the sixth, and usually the last-mentioned mechanical power. Like the wedge, it is founded on the principle of the inclined plane.

152. The screw consists of a projecting ridge winding in the form of an inclined plane, and in a spiral direction, round a central cylinder or spindle, similar to a spiral road winding round a precipitous mountain. Fig. 51 is a representation of a common strong screw used in various mechanical operations. The projecting ridge on the spindle is technically called the *thread*. The thread is not always made in this square projecting form; it is frequently sharpened to a single thin edge, as in fig. 54; but this does not affect the principle of the machine.

Fig. 51.

153. One circumvolution or turn of a thread of a screw is, in scientific language, termed a *helix* (plural *helices*), from a Greek word signifying winding or wreathing. The spiral winding of the thread is called the *helical line*.

154. The turns of a screw do not necessarily require to have a central spindle. They may form a screw of themselves, and do so in the case of the common cork-screw (fig. 52). A screw of this pointed or tapering form, in penetrating a substance, possesses the advantage of the inclined plane in three ways; first, by the gradual thickening of the substance of the thread from a sharp point; second, the gradual widening, and, third, the gradual ascending, of the thread.

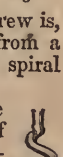

Fig. 52.

POWERS OF THE SCREW.

155. The screw acts on the principle of the inclined plane, and this is obvious from the consideration of the nature of the threads. If we were to cut through the turns of the threads straight from top to bottom, and draw them out to their full extent, each separate, and retaining its own inclination, we should find that they were so many inclined planes. In the annexed cut, fig. 53, one entire turn of the thread is thus drawn out, reaching from *b* to *a*, and is seen to form an inclined plane. If not drawn out, it would wind down to *c*; therefore, while a weight is raised by one turn of the screw

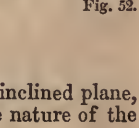

Fig. 53.

over the limits of one thread, or from *c* to *b*, it has actually been carried up the inclined plane from *a* to *b*.

156. The screw has no power by itself. It can operate only by means of pressure against the threads of another screw which overlaps it and holds it. This exterior screw, which is technically called a *box* or a *nut*, consists of a block with a central tube cut out in spiral grooves so as to fit with perfect exactness with the screw which has to work in it. Fig. 54 represents both screws in combination. M is the box or nut through which the screw passes. L is a lever inserted into the head of the screw, for the purpose of turning it.

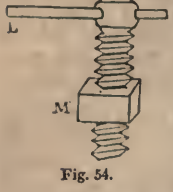

Fig. 54.

157. The object required by the use of the screw is to apply force or pressure. To produce the intended effect, either the outer or inner screw—that is, either the nut or the screw—must be fixed. If the screw be fixed at one extremity—say at the top—to a solid body, the nut may be turned round it so as to move from the bottom to the top; and if the nut be fixed, held fast by some solid body, the screw in the same manner may be turned round till it reach its extremity. Thus either the point of the screw or the nut may be forced in such a way as to squeeze or press any object presented to them.

158. Practically, the screw is never used as a simple machine; the power being always applied by means of a lever passing either through the head of the screw or through the nut. The screw, therefore, acts with the combined power of the lever and inclined plane; and in investigating the effects, we must take into account both these simple mechanical powers, so that the screw now becomes really a compound machine.

159. In the inclined plane, as has been seen, the less it is inclined, the more easy is the ascent, though the slower is the process of rising to a certain elevation. In applying the same principle to the screw, it is obvious that the greater the distance is betwixt the threads, the greater or more rapid is the inclination, and, consequently, the greater must be the power to turn it under a given weight. On the contrary, if the thread inclines downwards but slightly, it will describe a greater number of revolutions in a given space, so as to diminish the distance betwixt the threads, and the smaller will be the power required to turn the machine under a given weight. Therefore, the finer the screw, or the nearer the threads to each other, the less the power will require to be for a given resistance.

160. Suppose a case of two screws, one having the threads one inch apart, and the other half an inch apart; then the force which the first screw will give with the same power at the lever, will be only half that given by the second. The second screw must be turned twice as many times round as the first, to go through the same space. At the lever of the first, two men would raise a weight to a given height by making one revolution; while at the lever of the second, one man would raise the same weight to the same height by making two revolutions.

161. It is apparent that the length of the inclined plane up which a body moves in one revolution is the circumference of the screw, and its height the interval between the threads. The proportion of the power would therefore be—"as the circumference of the screw is to the distance between the threads, so is the weight to the power." By this rule, the power of the screw could alone be found, provided the action of the machine was not affected by the lever which works it. As that is the case, the circumference described by the outer end of the lever employed is taken instead of the circumference of the screw itself.

RULES FOR CALCULATING THE POWERS OF THE SCREW.

162. The rule by which the true force of the screw is calculated is, by multiplying the circumference which the lever describes by the power. Thus—THE POWER MULTIPLIED BY THE CIRCUMFERENCE WHICH IT DESCRIBES IS EQUAL TO THE WEIGHT OR RESISTANCE, MULTIPLIED BY THE DISTANCE BETWEEN TWO CONTIGUOUS THREADS. Hence the efficacy of the screw may be increased by increasing the length of the lever by which it is turned, or by diminishing the distance between the threads. If, then, we know the length of the lever, the distance between the threads, and the weight to be raised, we can readily calculate the power; or, the power being given, and the distance of the threads and the length of the lever known, we can estimate the weight which the screw will raise.

163. Suppose the length of the lever to be forty inches, the distance of the threads one inch, and the weight 8000; required —the power, at the end of the lever, to raise the weight. The lever being 40 inches, the diameter of the circle which the lever describes is double that, or 80 inches. Reckoning the circumference at thrice the diameter (though it is a little more), we multiply 80 by 3, which gives 240 inches for the circumference of the circle. The distance of the threads is one inch, and the weight 8000 pounds. To find the power,

multiply the weight by the distance of the threads, and divide by the circumference of the circle—

8000 weight
1 distance

240)8000

$33\frac{1}{3}$

164. *Thirty-three and a third* is the product, and it would require that power or number of pounds to raise the weight. This, however, is only in theory. In practice, a third of the amount of power would require to be added to overcome the friction of the machine.

165. In the ordinary working of the screw, velocity is incompatible with great power. This is a truth, however, which applies only to a screw with one thread. There is a way of making a screw, by which great velocity and power may be combined. This is done by forming the screw with two, three, or more threads. To understand how this is accomplished, we have only to conceive the idea of a screw with one thread, very wide betwixt its turns, and then imagine one or two other threads placed so as to fill up the intervals; thus composing a fine close screw. And as by this means all the threads descend with equal rapidity, we have a screw which will not only descend with great velocity, but which will apply a very great degree of pressure. A screw of this nature is used in the printing press, by which a pressure of a ton weight is applied instantaneously by a single pull of a lever.

EXAMPLES OF SCREW POWERS.

166. The most common purpose for which the screw is applied in mechanical operations, is to produce great pressure, accompanied with constancy of action, or retention of the pressure; and this quality of constancy is always procurable from the great friction which takes place in the pressure of the threads on the nut, or any substance, such as wood, through which the screw penetrates.

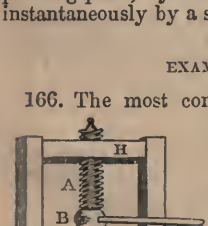

Fig. 55.

167. The common standing-press used by bookbinders for pressing their books, affords one of the best examples of the application of the screw to produce great pressure (fig.

55). The screw A has a thick round lower extremity B, into holes in which the lever is inserted. This extremity B is attached by a socket joint to the pressing table C, so that when the screw is turned in one direction, the table sinks, and when turned in another, the table rises. The books D lie upon a fixed sole S, and are thus between the table and the sole. H is a cross beam above, in which is the box or overlapping screw to give the necessary resistance.

168. The force of the screw is sometimes employed to turn a wheel by acting on its teeth, by which means there is a combination of two mechanical powers—the screw, and the wheel and axle (fig. 56). The screw is upon the horizontal spindle, and by turning it by the handle, each turn of the thread receives a tooth of the wheel and brings it forward, so as to produce a perpetual revolution of the wheel. This is called an endless screw, because it never stops in its action; no sooner is one turn of the thread disengaged, than another has come into operation. W represents a weight to be raised hanging from the circumference of the axle.

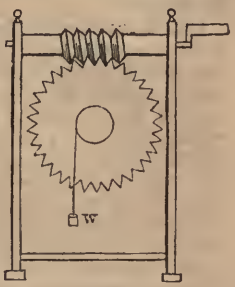

Fig. 56.

169. The screw concludes the list of simple mechanical powers, according to the usual definitions of science. But, to prevent misconception, it has to be noted that there are other means and agents of force in nature besides those comprehended in the number of simple mechanical powers working by solids. These will come under observation in the subsequent departments of Natural Philosophy.

MECHANICAL COMBINATION AND STRUCTURE.

GENERAL EXPLANATIONS.

170. Mechanical action, as already stated (3), is applied to the action of forces that produce no change in the constitution of bodies, and is therefore distinguished from chemical or any

other species of action, in which change of constitution is less or more effected.

171. Great changes are continually taking place in nature and art by mechanical action. Mechanical action generally implies movement or change of place, and in most cases alteration of external features and circumstances. The whole of the planetary movements are mechanical; the motions of water and winds are mechanical; and the new appearances produced in art by placing different objects together are mechanical.

172. The action of forces upon solids, or mechanical action, is taken advantage of by mankind for the production of numerous useful results in the arts. And success in attaining these results depends in a great measure upon the knowledge we have of the principles of Mechanics, and the skill and care we use in applying them.

173. When skill, care, and ingenuity are brought fully into operation for these results, very great wonders are in many instances achieved. But where there is ignorance or negligence, the object in view may not only be defeated, but very mischievous consequences may take place.

174. Example I.—If a tall mast or beam break through at two-thirds of its height, and the two fractured ends be simply placed together and tied with a rope, the upper piece will, by the action of a small force, again fall. It will act like *the arm of power of a lever* against the rope, which is the *weight;* and as this weight is inconsiderable, the arm of power will preponderate. But if we take the two pieces and saw each of them lengthwise, so as to make four pieces, and then, as represented in fig. 57, lay a short piece alongside of a long piece, and another long piece on the top of the first short piece, with the second short piece opposite to this second long piece, the whole will be effectually *spliced* together; in such a case, with the aid of an overlapping rope, the beam will in all likelihood be stronger than it was before it was fractured. The cause of its being stronger, at least of its remaining firm, is, that the weaker part at one side is supported by a stronger part on the other side. Thus, by skilfully taking advantage of certain forces acting in connection with solids, we are able to rear a structure of the utmost possible strength.

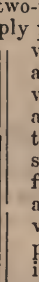

Fig. 57.

175. Example II.—If a man, in making repairs upon the outside of a building, project a plank from a window for the purpose of standing upon it, and if he proceed to place himself near the outer extremity of the plank, without having

placed a sufficient counterbalancing weight at its inner extremity, he will assuredly be precipitated to the ground, and perhaps killed; because the *gravity* of his body acted like a *power* on the arm of a lever, while the lever was without a sufficient *weight* to preserve the apparatus in equilibrium. From such neglects of the operation of forces in nature, dreadful consequences frequently ensue.

176. The study of the operation of mechanical forces, along with experience, teaches that there are certain bulks, positions, and forms of bodies which produce the greatest strength for purposes of art.

177. The strength of beams or masses of the same kind and bulk, and fixed in the same manner, in resisting a transverse force which tends to break them, is simply as their breadth, as the square of their depth, and inversely as their length—that is, the thicker and shorter they are, they are the stronger. Thus, if a beam be twice as broad as another, it will also be twice as strong; for the increase of breadth doubles the number of the resisting particles. By making the beam double the depth, the strength is four times as great; because the number of fibres is doubled, and the lever by which they act is also increased.

178. But this increase of strength, by increasing bulk, has a practical limit. It is found that in increasing the dimensions of a body, or combination of bodies, preserving all proportions the same, *the weight increases more rapidly than the increase of strength, or power of endurance.* This is one of the most important principles in mechanical science, and ought to prevent undue extension in structural arrangements (39).

179. Take a block of stone, and fix one end of it into a wall, leaving its other end projecting. By this arrangement of position, each particle of matter in the block acts as a weight pulling downwards as with a lever, the fulcrum of the lever being at the point of support, and the particles of matter in the mass forming at once the arm of power and the weight. Hence every particle we add to the length of the block adds to the length of the arm of the lever, and increases the weight. If we add to the block beyond a certain length (whatever may be its constitutional strength), we shall certainly cause the mass to break and fall, from the effect of gravity, upon the outer extremity.

180. A similar lever action takes effect in the case of blocks or beams supported at both ends, the only difference being, that, in extending them to an undue length, they will break in the middle, or at the weakest point between the two supports.

181. The strength of a beam supported at both ends is twice

as great as that of a beam of half the length, which is fixed only at one end; and the strength of the whole beam is again increased if both ends or fulcra be firmly fixed, as into a wall.

182. In the case of fibrous or grained materials, as, for instance, wood, the body sustains the greatest pressure when the weight is applied to the grain endwise, or to the beam longitudinally. The nearer that the pressure can be applied to any beam endwise, the better. Thus, a beam supports most weight on its upper end, the other end being fixed to the ground, and its strength is next greatest when the pressure is applied to it leaning at top against another beam. This is exemplified in the angular roofs of houses, in which two beams lean against each other like the two sides of the letter A. In arranging beams to support great weights, as in building bridges, each beam is made to push obliquely upward with one end, while it pushes obliquely downward with the other, and thus an extensive combination of beams is firmly supported.

183. In rearing structures consisting of beams, it is an important point to convert, as far as possible, by mode of erection, cross or transverse strains into longitudinal strains, or into forces acting on the ends of beams in the direction of their length.

184. Nature appears to have designed that strength of structure should be accomplished with the least expenditure of material. It is obvious that, if trees and animals were made many times larger than we now find them, and of the same kinds of substance, they would be borne down by their own weight. Small animals endure greater comparative violence, and perform greater feats of strength, in proportion to their size, than large ones. The largest bulk which a human being can possess in his person, at the same time retaining activity of motion, is not more than is usually seen in well-grown men. Thus, from a simple natural cause, men of very gigantic figure never could have existed on our earth. Men must always have been about the size which they are at present; or, if they were considerably larger, they must have been constituted of much stronger materials, without a corresponding increase of weight.

185. The same principles relative to mechanical strength apply to contrivances in the arts. As already stated, the strength or power of endurance in a material does not increase in proportion as the weight increases. Hence there is a practical limitation of the magnitude of machines and other structures. For example, a bridge or roof of beams may be very strong when of small or moderate size, but if the dimensions be extended beyond a certain limit, the structure will fall, by not being able to support its own weight.

186. The strength or power of endurance of pressure upon a

fixed body, is greatly increased by giving the body a certain form. The strongest form in nature or art is that of an *arch*.

ARCHED STRUCTURES.

187. An arch is a skilful disposition of parts, forming a convex and concave side, the convex side being that upon which the pressure is applied. The arch—which takes its name from *arcus*, a Latin word signifying a *bow*—may be either a portion of a circle or ellipse, or entirely rounded in form. Whether shaped like a bridge, a round tube, or the shell of an egg, the principle which causes the power of endurance of pressure is the same.

188. The principle of endurance consists in the particles of the arched body bearing upon each other like a series of wedges, thus causing a compression of particles on the concave side of the circle, which enables the mass to bear an enormous pressure on the convex side. Indeed the greater the pressure is (to a certain extent) perpendicular to the convexity, so also the compression and power of resistance become the greater.

189. In the case of arched objects which have to meet resistance on all sides, the circular form is best. In the case of objects such as arches of bridges, which are exposed to pressure chiefly on one side, the semicircular form is the strongest, or offers the greatest resistance. The more that the figure of an arch departs from the true circle, the weaker it becomes.

190. In arched forms, such as tubes or egg-shells, the compression of particles takes place all round the inside of the object, so that the arch presents a power of resistance at any part of its convexity; the power being always greatest where the bending or convexity is greatest. For example, it is more difficult to break an egg by pressing against the two ends than against the sides.

191. In the representation of a regular-sided wedge, fig. 58, to which the side pressures are applied at right angles to the sides, it is seen that the lines of direction of the two forces or pressures proceed obliquely to a point within the wedge. The same principle applies to the particles or blocks composing arches—the pressing forces meet in a point within the particles or blocks, and the situation of this point is governed by the degree of convexity of the arch—that is, the degree of inclination of the respective wedges.

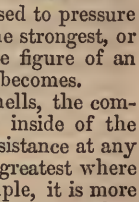

Fig. 58.

192. Hollow cylindrical tubes, shafts, pillars, or other objects of art, are much stronger than the same objects would be if

solid, with the same quantity of material. Plates of metal bent into grooves on the surface, are similarly much stronger than the same plates when flat. This is well exemplified in the roofing of the large warehouses and wharfs at the London Docks, which are covered with sheets of iron. The sheets are thin in substance, but bent into semicircular grooves and ridges, and have all the strength of thick plates without their dangerous weight.

193. In arched forms, such as bridges, in which there is only part of a circle or ellipse, the two extremities of the arch must rest against immovable piers or abutments, sufficiently strong to resist the horizontal thrust upon them; for it is upon these parts of the structure that the pressure takes effect.

194. Fig. 59 represents the simple elements of two arches.

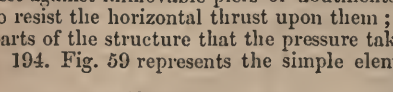

Fig. 59.

B is an outer pier fixed firmly on the ground. F is another pier, and betwixt the two there are two wedge-shaped stones, E and D, lying obliquely to each other. It is obvious that the more these two stones press downwards, they will more firmly sustain each other. The pier F serves as a prop to the other arch, which consists of G H I, and is supported at the outer extremity by the fixed pier K. The three stones in this arch press against each other in the same manner as in that with the two stones; and the same principle operates, although the arch consists of fifty or a hundred stones. The central stone of all arches is the stone which binds the mass together, as in the case of H, in the figure, and is technically called the *key-stone*. It is always the last inserted.

195. A similar action of mutual pressure to preserve equilibrium occurs in all arched forms. The human foot is an arch consisting of small bones bearing on each other, at once to give strength, lightness, and elasticity.

196. Anciently, bridges were built of a purely semicircular form, giving a considerable convexity or rise in the middle. This was an inconvenient form for a bridge. Architects now make bridges with elliptical or slightly-curved arches, so that the passage above them is, in most cases, as easy as along a piece of ordinary road. Although these modern slightly-curved arches are not strictly so strong as semicircular ones, they are sufficiently so for all necessary purposes.*

* A further consideration of the subject of strength of materials belongs to PRACTICAL MATHEMATICS.

ELEMENTS OF PRACTICAL MACHINERY.

197. The term *machine* is ordinarily applied to any piece of mechanism, in which different parts are combined to produce a desired effect. In NATURAL PHILOSOPHY, a machine of this nature is called a *complex machine* (4); and the treatment of the principles on which complex machines operate, constitutes that department termed PRACTICAL MACHINERY.

GENERAL DEFINITIONS.

198. The simple mechanical powers compose the elements of all machines, however complex or extensive. Thus, in all machines, levers, cords, or inclined planes, in their different modifications, are found to be the elementary parts, combined in harmonious union to accomplish certain results.

199. Machines are usually formed of wood, iron, steel, brass, or other durable materials, with sometimes leather and cordage as part of the apparatus.

200. In the construction of every machine, four objects are particularly desirable—1st, Strength or durability of materials; 2d, Simplicity of arrangement of parts; 3d, Exactness of fitting of one part to another; and, 4th, Easiness and correctness of motion. It is a general and well-recognised principle in mechanics, that the *fewer the parts* are in a machine, and the *more simple its construction*, the better.

201. Machines act from the impression of a certain power or force communicated to them. Whatever be the amount of power they receive, that amount they expend in their action. They cannot in the smallest degree increase the power. They can only convey, regulate, and distribute the quantity of power which has been communicated to them.

202. The power communicated to machines is derived from various sources; as, human labour, the power of horses or other animals, the force of wind, water, or steam, or any other active agent which may be found suitable. Sources of power are technically called *moving forces*, or *first movers*.

203. Of the original impressed power, each moving part of the machine uses a certain portion. If the whole power which enters a machine be supposed to consist of 1000 parts, this large quantity is dispersed in various small quantities through the mechanism; some wheels taking perhaps 10 parts, others 5 parts, a third kind 1 part, a fourth a fractional part, friction another part, and so on, till the whole 1000 parts are expended.

In some large cotton, flax, or silk-spinning establishments, a single water-wheel or steam-engine turns several thousands of spindles; each spindle consequently consumes a minute fraction of the originally-impressed power.

204. Whatever be the nature of the moving forces, it is generally sufficient for all purposes that they produce, in the first instance, *rotary* or *circular motion*, and either in a horizontal or vertical direction. It is, however, indispensable that the power be of that magnitude which will cause each part of the machine to fulfil its assigned office. If the power be too small or weak, the machine will move languidly and ineffectually; and if too great, it will either cause the machine to move too rapidly, or at least power will be expended uselessly. In the application of moving forces, it is always a matter of importance to regulate the power to the precise wants of the machinery.

205. The circular motion communicated, in the first instance, to a machine, is, by means of certain contrivances, diffused through the whole organisation, and changed into every conceivable direction; some parts being caused to revolve, others to rise and fall, a third kind to move horizontally to and fro, and so forth, in all possible ways. The various parts may also be made to move with any degree of velocity; there being methods of transforming quick into slow motion, or slow motion into quick. Very minute and complex operations are thus performed by machines with a precision which often exceeds the skill of the most expert artisan; but these operations are all necessarily marked by the quality of *uniformity of action*.

206. As machines cannot reason, or act arbitrarily in stopping, moving, or altering their process, according to circumstances, they proceed in a blind routine, whether right or wrong, *mechanically* as it is called, and in every case less or more require the superintendence of reasoning beings. This apparent defect, however, is really advantageous. A machine, by being composed of inanimate matter, destitute of feeling, and unsusceptible of fatigue, proceeds unswervingly, and may be forced to accomplish tasks which it would be both inhumane and impolitic to demand from living creatures.

207. The purpose of machinery, therefore, is to *lessen and aid human labour*. At an inconsiderable expense, and with a small degree of trouble in supervision, a machine may be made to do the work of ten, fifty, or perhaps as many as five hundred men; and the work so simply effected by inanimate mechanism, serves to cheapen and extend the comforts and luxuries of life to the great body of the people.

The following are the chief elementary parts of machinery :—

SHAFTS.

208. The axles on which wheels and pulleys are supported are termed *shafts* and *spindles;* the former being applied to axles of large, the latter to those of small, dimensions. Shafts are of two kinds—*horizontal* and *vertical.* In fig. 60, *a b c*

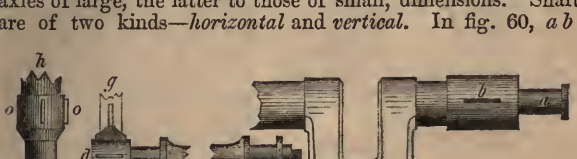

Fig. 60.

is part of a horizontal shaft; *h i*, part of a vertical. The latter is generally used for conveying motion from the lower to the upper part of a machine, or from one story of a mill or factory to the other. The part of a shaft on which it revolves is termed the *journal* or *bearing;* in heavy mill-shafts it is termed sometimes the *gudgeon.* In fig. 60, *a* is the journal of the horizontal shaft *a b c.* The journal is formed by turning the shaft to a less dimension than the adjacent parts; thus forming a projection at each end. These projections, as at *f*, are called *ruffs* or *collars.* The part of the shaft on which the wheel is to be fixed is termed the *boss*, as *b* in the horizontal shaft *a b c*, and *o o* in the vertical one, fig. 60. The wheel or pulley is fastened firmly on by what are called *keys.* A groove or slit is cut in the inside of the *eye* of the wheel or pulley, generally in two places at the extremities of the diameter. Part of the periphery of the boss of shaft is levelled or made flat, at places corresponding to the position of grooves in the eye of the wheel or pulley. The wheel or pulley is then passed on to the boss of the shaft, and the grooves and flat spaces, called *key-seats*, made to coincide. Keys or wedges are then driven into the grooves very tightly, and the wheel or pulley is thus prevented from slipping or turning round on the shaft. In fig. 60, *f e d* is part of a spindle or small shaft; *f e* are the journals, *d* is the boss, *g g* represents part of a pulley keyed on to the boss. In *h i*, which is part of a vertical shaft, *o o* is the boss, and *i* the bearing.

PEDESTALS, OR PLUMMET-BLOCKS, FOR HORIZONTAL SHAFTS.

209. To support the shafts while in motion, *pedestals* or *plummet-blocks* are used. In fig. 61, towards the right-hand side of the centre line of the upper figure, we give a half front-elevation of a plummet-block or pedestal; *a a*, the body, is bolted down to the base of the machine by the bolts *b b*. The journal of the shaft is embraced by what are known as *brasses, bushes*, or *steps*, made in two pieces or halves. The lower one, on which the shaft rests, is placed in the body of the block, as *f*; a space being there made for it, as *f'*. The upper brass *g*, is placed in the cover or cap, *c c*, of the pedestal; a space, *g'*, being made therein for its reception. The cover or cap *c c* is bolted down to the body of the block by the bolts *d d*, which pass through holes, as shewn in the sketch. Fig. 62 is the plan of the pedestal, shewing the shaft *e e* in its place, with cap *c c* screwed

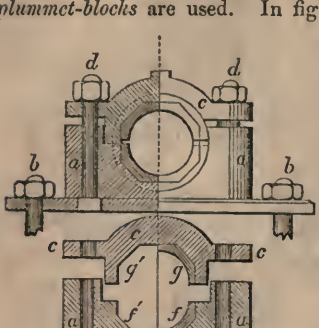

Fig. 61.

Fig. 62.

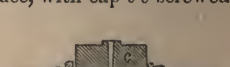

Fig. 63.

down. Fig. 63 is a transverse section, shewing the relative position of the shaft *e e*, with the ruffs or collars *a' a'*, the body *a* of the pedestal, cap *c*, and brasses *f f*, *g g*. Fig. 64 gives different views of the brasses: *a* is a front-view of the upper brass, *c* a side-elevation of the same, and *a'* a section; *b* is an elevation, *d* a side-view, and *b* a section of the lower brass; *e* is a plan of both the upper and lower brasses. The breadth of pedestal, body, and cap is such, that they go easily within

the projecting flanges, *f f*, of the brasses, as shewn in fig. 64: the brasses are thus prevented from sliding out laterally from the block, as they would be apt to do if not furnished with flanges. The following is the method of fitting-up this arrangement of pedestal:—The body being firmly screwed down and adjusted on its base by the screws *b b*, fig. 61, the lower brass *b*, fig. 64, is put in its place *f f'*, fig. 61; the shaft is then lifted in, so that its journal shall rest in the lower brass, as in fig. 63. The upper brass is then made to embrace the upper side of the journal, and the cap *c c* is next passed over it. The bolts *d d* being previously passed up the apertures in the body of the block, before screwing the same down to its base, these pass through the apertures in the cap by screwing the nuts down; the cap is made to press on the upper brass, which is thus made to embrace tightly the journal of the shaft. This is lubricated by the oil passed down the hole made in the centre of the cap. As the brasses wear away, and the journal works loose in its bearing, they are tightened by screwing down the cap *c c* by the nuts *d d*.

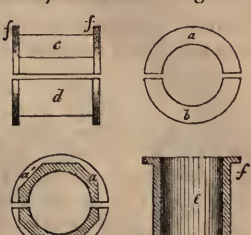

Fig. 64.

HANGERS, OR SUSPENSION-BEARINGS.

210. The arrangement described in last paragraph is that used in cases where a base is obtained resting upon the ground. Shafts are sometimes required to revolve beneath the ceiling, in order to convey power from one point to another of a building, without interfering with arrangements on the floor below. In this case, *hangers* are used, as shewn in fig. 65. Let *c c* represent the line of ceiling; the suspension-bearing is bolted to this, as *b b*: *a* represents the shaft, *d* the brasses in which it revolves. The fitting-up is similar to that described in last figure. Shafts sometimes are led along the face of a wall; in this case the bearings are placed on a bracket, which is bolted to and projects from the wall.

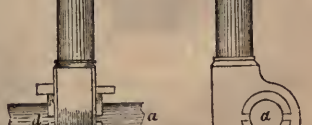

Fig. 65.

STEPS OR BEARINGS FOR VERTICAL SHAFTS.

211. A brass block *e*, fig. 66, is placed in the interior of a cast-iron box *b b*, *a a*, which is bolted firmly down to the base, on which the step is supported, generally a block of stone. The position of the brass block *e* is adjusted accurately within the box, so as to make the shaft perfectly vertical, by the adjusting-screws *b b*. A hollow is made in the brass *c*, in which the end of the shaft, as *i*, fig. 60, revolves; it being well lubricated by oil poured in, or by tallow which is placed in a space furnished for it in the side of the brass *e*. In this form of *step* for a vertical shaft, the height of the brass *c*, once adjusted, remains permanently so. In flour-mills, however, the vertical shaft which supports the grinding-stone is capable of being raised or lowered, so as to bring one stone nearer to the other, or *vice versâ*, according to the fineness of the flour required. This capability of adjustment is attained by making the end of the shaft *a*, fig. 67, revolve in contact with the end of a block *d*, which is capable of being raised or lowered by an appropriate arrangement of levers. The lower end of the vertical shaft is embraced by a brass *c c*, driven in between the shaft and the box *b b*. Oil in this form is admitted to lubricate the shaft, through a pipe, shewn in a sloping direction in the drawing.

Fig. 66.

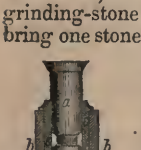

Fig. 67.

COUPLINGS FOR SHAFTS.

212. When the distance to which motion is to be communicated is too great for the employment of one shaft, the several lengths required are joined together by contrivances known as *couplings*. In fig. 68, the *square-box coupling* is illustrated. The two shafts *a b* are faced up square at the end; and when brought together, a square box *c c* is passed over, and made to embrace them, and the whole secured by driving in keys or wedges into key-seats previously formed in the box *c c*. The *round coupling*—which is the most generally used—is illustrated in fig. 69: in this case, the shafts *a b*, at their terminations, are circular — not square, as in

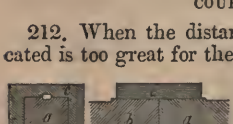

Fig. 68.

Fig. 69.

fig. 68; the coupling-box *c c*, also circular, is fastened within by keys, as in the drawing; or by two pins passed through the box and shaft at right angles to each other, and firmly riveted into countersunk holes made in the box *c c*: this is shewn in the sketch to the left of fig. 70. In place of bringing up the ends of the shafts square to each other, the shafts are made to be still more firmly united by making them lock into each other, as it were, by means of the arrangement shewn in fig. 70, and known as the *half-lap joint*. The coupling-box in this case is round.

Fig. 70.

TOOTHED WHEELS.

213. Toothed gearing is divided into two classes—spur-wheel, spur-wheel and pinion, and bevelled gear. Fig. 71 represents

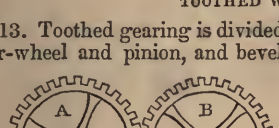

Fig. 71.

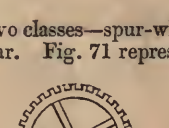

Fig. 72.

two spur-wheels in gear; fig. 72, a spur-wheel and pinion; and fig. 83, two bevelled wheels in gear. In the working of toothed wheels one upon another, or of wheels working on pinions, it is essential to set them in opposition with such exact adjustment that the teeth of one will fall into the hollows betwixt the teeth of the other. When the teeth of each do not work with this nicety, they are apt to jar upon and break each other, and so damage the machine. In some cases, teeth are made of a round or pointed form at their extremities, by which a very small degree of grinding or pressing on each other takes place. Fig. 73 is an example of a wheel and pinion with rounded and pointed teeth. From the centre of the axis of the pinion L to the centre of the wheel C, a dotted line is marked, called by mechanics the *line of centres*. The dotted circle O O round the pinion, and the dotted circle P P round the wheel, indicate the true point of working or contact of the

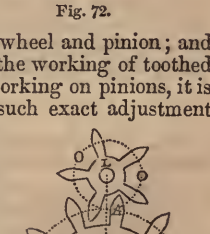

Fig. 73.

teeth upon each other. These two circles are seen to join with exactness at A. The true curve to be given to the teeth of spur-gearing is the epicycloid; which is the curve generated by the rolling of one circle round another—a point in the circumference of the rolling circle describing the curve. The true curve of the teeth of bevel-wheels is the spherical epicycloid generated by a point in the circumference of a cone, which rolls on the circumference of another cone.

PULLEYS.

214. When motion is transferred from one point to another by means of belts, chains, &c., pulleys are used. In fig. 74, *a*

Fig. 74.

is the front, and *b* the edge view of the pulley used with the flat leather belt. The periphery of the pulley is made convex; this prevents the belt from slipping off, as its tendency is always to keep to the highest part: *c e* are sections of a pulley, shewing the method of fixing on the shaft; *d* is the form of pulley used when chains or ropes are made to transmit the power.

RATCHET-WHEELS.

215. It is sometimes necessary to prevent wheels and axles, bearing the strain of heavy weights, from flying in a backward motion after being wound up. This purpose is effected by fixing a ratchet-wheel to the extremity of the axle. This wheel has teeth all round its periphery, inclining in one direction; and a small catch is so placed as to enter the indentations, and stop the wheel if it inclines to turn backwards; but the catch slides over the teeth without obstructing them, if it moves forward. A spring pressing on the catch causes it to keep in its proper place (fig. 75).

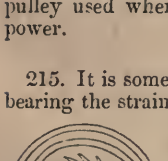

Fig. 75.

CRANKS.

216. A crank resembles a common handle or winch for turning a machine by the hand; the chief difference being

that a rod or shaft jointed to the handle, and going up and down, works the machine. If the crank be made double, it will turn two wheels or machines. Fig. 76 represents a double crank in action. S is the rod or shaft ascending and descending, and attached by a joint to the lower part of the crank C, which it alternately pulls up and pushes down, so as to cause the axles W W to turn a wheel at each side.

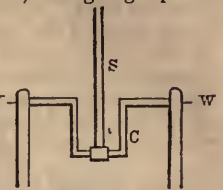

Fig. 76.

Fig. 77.

Take away one of the sides of the crank and its support, and the apparatus becomes a single crank. In fig. 77, we give a section of the crank of the steam-engine illustrated in the chapter on the mechanism of the steam-engine. *c* is the crank keyed on to the boss *b* of the shaft *a*; *d* is the crank-pin, to which the connecting-rod is attached, which gives motion to the crank-shaft *a*.

CONNECTING-RODS.

217. In various mechanical movements, motion is communicated from one point to another by means of connecting-rods: thus, in fig. 113, the motion of the piston-rod *d* is communicated to the crank *h*, by the connecting-rod *g g*. The details of this part of mechanism are shewn in figs. 78, 79, and 80. In fig. 79, *a a* is the front-view of *butt* of upper end of connecting-rod, and *a′ a′* the side-view; *c c* the side-view of the strap, and *c′ c′* the front-view. The journal *f*, fig. 78, is embraced by two brasses, the upper of which is shewn at *a*, fig. 80, and the lower at *b*; *a′* and *b′* being side-views of these: in fig. 78, *g* is the lower, and *h* the upper brass. The following is the method of fitting-up the connecting-rod and crank-pin.

Fig. 78.

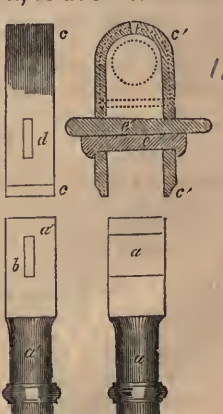

Fig. 79.

The crank-pin journal *f* is embraced by the lower and upper brasses; the strap *c c*, *c′ c′*, fig. 79, is then passed over these, so as to make the upper and circular end of the strap *c c*, press upon the upper brass. The butt, *a a*, is then passed between the fork or sides of the strap *c c*; the square end of the butt pressing against the flat side of the under brass, as *c*, fig. 80. To keep the whole together, the gib *c*, and key *c′*, are passed through the slot or aperture *d*, which passes at corresponding points through the strap and butt. As the brasses wear down, they are made to embrace the journal of the crank-pin tightly by driving up the key *c′*; this brings down the strap *c c* to press upon the upper brass, and the butt to press upwards on the under brass.

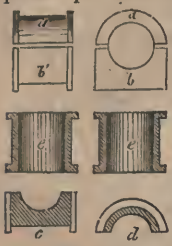

Fig. 80.

In fig. 80, *d* shews a section, and *c* a plan of the upper brass *a*; and *c* a section, and *c′* a plan, of the lower brass *b*.

ECCENTRICS.

218. An eccentric is a wheel or pulley, with the axis out of the true centre. The construction of this is shewn in fig. 81.

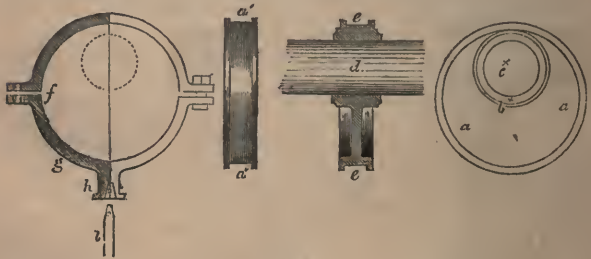

Fig. 81.

It consists of a pulley, as shewn at the side-view, as *a a*; the periphery of which is grooved, as shewn at the edge-view at *a′ a′*. The true centre is at *b*, but the working-centre, or that through which the axis or shaft *d* passes, is at *c*. In the course of its revolution, any point on its circumference will alternately rise and fall; the extent of which rise or fall is just double the distance which the centre *c* is from the true centre *b*. To communicate this alternate motion to any part, as to the rod *l*, the following arrangement is adopted:—An upper hoop *f*, and a lower one *g*, are made to embrace the

periphery of the eccentric; their breadth being such as to pass easily within the groove $a' a'$ of the eccentric; the two hoops are bolted together, and the end of the eccentric-rod l, to which motion is to be given, is keyed into the eye h, formed on the under side of the lower hoop. To decrease the friction, small pieces of brass, of the same curve as the periphery of eccentric, are riveted in the inside of the hoops, at three points in each hoop; the eccentric, therefore, revolves in contact with these pieces of brass, which are kept well lubricated; the oil for this purpose being passed through an aperture made through the centre of the upper hoop.

219. Having now shewn the construction and arrangement of the various parts of practical mechanism, as practically adopted, we proceed to explain the varieties of mechanical movements by which motion is transferred or changed in its character, according to the work which is required to be performed.

ALTERING THE DIRECTION OF MOTION.

220. Motion often requires to be *altered in its direction* in the course of its transmission. For example, rotary horizontal motion requires to impart rotary vertical motion, or rotary vertical motion to impart horizontal motion. By means of a peculiar mode of setting the wheels, and a corresponding peculiarity in the shape of their teeth, any alteration may be effected in the direction of the motion.

221. Fig. 82 represents a plan of changing the direction of motion. A is a pinion or trundle working with its shaft horizontally on a wheel B, whose shaft is turning vertically. As the case may happen to be, the horizontal movement is causing the vertical movement, or the vertical movement is causing the horizontal movement.

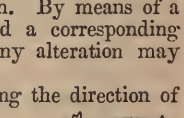

Fig. 82.

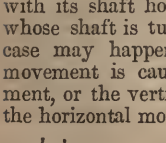
Fig. 83.

222. Fig. 83 represents a more common plan of changing the direction of motion. The wheels in this case are bevelled. A *bevel*-wheel is a wheel with teeth placed in a sloping or oblique direction on its circumference. When two bevel-wheels are placed at right angles to each other, their respective teeth work against each other, and so a harmonious joint-motion ensues. This is exemplified in the figure, in which a horizontal shaft with a bevel-wheel is seen turning a smaller bevel-wheel above it, placed on a vertical shaft.

223. Where two pulleys work together by means of belts or driving-straps, the driven pulley moves in the same direction as the driving: to change the direction of the driven pulley, all that is necessary to be done is to cross the belt, as illustrated by fig. 84. The same change of direction is effected by using spur-wheels, as in fig. 71; the driven wheel revolving in the opposite direction from that of the driving.

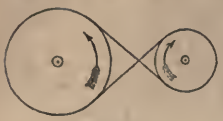

Fig. 84.

ALTERING THE VELOCITY OF MOTION.

224. Where the driven shaft is required to move at a different velocity to that of the driving, it may be effected either by the use of pulleys or toothed wheels of different diameters. Thus, in fig. 72, the pinion P on the driven shaft revolves at a much quicker rate than the wheel W on the driving-shaft; or, suppose P to be the driver, the driven wheel W will revolve very much slower. Again, in fig. 84, the small pulley, which we will suppose to be the driven, will revolve much quicker than the driving-pulley.

225. Any degree of velocity greater than that of the first rotary motion, may be imparted to the parts of a machine, by making these parts so much smaller than the primary moving parts. Thus, if a large wheel, having a thousand teeth in its circumference, work upon and turn a small wheel having only ten teeth in its circumference, the small wheel will go round one time for every ten teeth of the large wheel which it touches; or, in other words, it will go round one hundred times for one time of the large wheel. The respective velocities of wheels in a machine are, in this manner, always proportionate to their diameters or size, unless when specially arranged to be otherwise.

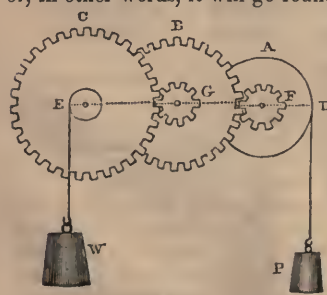

Fig. 85.

226. By using the combination of wheels shewn in fig. 85, a wide range in the change of velocity may be obtained. Thus, suppose the wheel E C to revolve twenty times per minute, and the pinion G, which gears into it, to be one-third of the diameter of E C, one revolution of

E C will give three revolutions to G. E C, 20, gives G 60 revolutions per minute. On the shaft of G, a spur-wheel, B, is fixed, which gears into a pinion F; for one revolution of B, let us suppose F makes, as before, three; B has 60, and gives 180 revolutions per minute. By this arrangement, therefore, F makes 180 revolutions for 20 of E C.

PRESERVING THE DIRECTION OF THE ORIGINAL MOTION.

227. Where two wheels, as in fig. 71, gear together, they revolve in opposite directions—the driven opposite to the driving. By adopting the contrivance of the *annular-wheel*, as in fig. 86, the motion of the driven wheel *a a d* is the same as that of the driving-wheel *b*. By placing a third wheel between two toothed wheels, the motion of the third wheel is the same as that of the first; thus, in fig. 85, the direction of motion of F is the same as that of A. E C

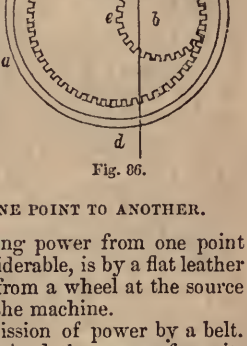

Fig. 86.

TRANSMISSION OF POWER FROM ONE POINT TO ANOTHER.

228. A common plan of transmitting power from one point to another, when the interval is considerable, is by a flat leather band, strap, or belt, communicating from a wheel at the source of power to a wheel connected with the machine.

229. Fig. 87 represents the transmission of power by a belt. A is the first pulley, which has received the power from its source, and C is the second pulley, moved by a belt, which passes over both pulleys. In this case, the motion of A is transmitted by the belt to C, which it causes to turn in the same direction as A. If these two pulleys were of precisely the same diameter, and the belt did not relax or slip, the second pulley would unavoidably go at the same velocity as the first, because the belt has exactly the property of a toothed wheel, and simply transmits the power it has acquired. As C appears to be somewhat smaller than A, it would consequently turn more frequently than A; therefore we have here an example of the mode of increasing the velocity while transmitting power.

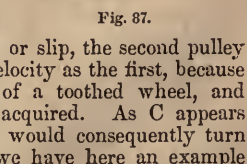

Fig. 87.

230. Fig. 88 represents an apparatus of a shaft and pulleys. A is the pulley receiving motion from the source of power, and, by means of the belt L, turns the pulley B on the end of the shaft S. At the same time, the pulley D at the opposite end of the shaft is turned. From a pulley on the shaft situated close to B, a belt descends to turn C, and from D another belt descends to turn E. Thus an extended axle or shaft from C will turn a machine, and an extended axle or shaft from E will turn another machine. The apparatus can turn two machines.

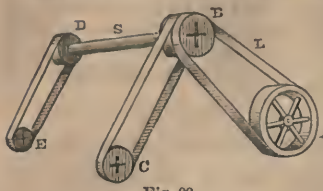

Fig. 88.

231. For transmitting power from one point to another, levers and connecting-rods are also used. Thus, in collieries a pump-plunger is worked, at some distance from the source of power, by a rod, or series of rods, with a bell-crank lever. In fig. 113, the power of the piston-rod *d*, is transmitted to the crank *h*, by the connecting-rod *g g*. For the transmission of power from one point to another, linked chains are used where a belt would be too weak for the power to be transmitted; the chain consists of a series of open links, with square or oblong spaces between each link. In passing over the pulleys, these links fall on to projections made in the periphery of the driving-pulleys; similar projections are made on the periphery of the driven pulley, which go, in like manner, between the spaces in the chain. The power of the driving-pulley is thus communicated to the driven in a way which is capable of resisting great strains.

CHANGING OR VARYING THE VELOCITY OF MOTION.

232. It is sometimes necessary that a machine, or part of a machine, should be propelled with a velocity which is not equable, and is continually changing from fast to slow, and slow to fast. This happens in cotton-mills, where it is necessary that the speed of certain parts of the machinery should continually decrease from the beginning to the end of an operation. To effect this, an apparatus is used, as represented in fig. 89. Two cones, or conically-shaped drums, are used, having their larger diameters in contrary directions. They are connected by a belt, which is so

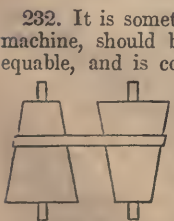
Fig. 89.

governed by proper mechanism, that it is gradually shifted along from one extremity of the cones to the other, thus acting upon circles of different diameter, causing a continual change of velocity in the driven cone with relation to that which drives it. The shifting of bands from large to small wheels, and from small to large, has similar effects.

233. The *cone-pulleys*—or speed-pulleys, as they are usually termed—is another way of effecting the same change of velocity. Thus, in fig. 90, by passing over the pulleys *c* and *d*, the motion of the shaft *d f* will be slower than that of the driving-shaft *a c*; by passing the belt over *b* and *e*, the diameters being equal, the velocity will be equal; over *a* and *f*, the velocity of *f d* will be greater than that of *a c*.

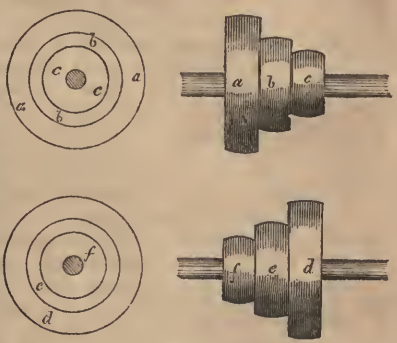

Fig. 90.

234. A variable velocity is obtained by the working of two elliptical toothed wheels, the centres of which are in the foci. By placing the shaft of the face or crown wheel B, fig. 82, eccentric to the wheel, and by lengthening the pinion A so as to enable the crown-wheel to act upon it during the whole of its revolution; the uniform motion of the pinion A will give a varying velocity to the crown-wheel B—the velocity being greatest when the teeth nearest the centre are gearing with the pinion A; and *vice versâ*.

INTERMITTENT AND ALTERNATING MOTIONS.

235. (1.) Supposing the pinion *a*, fig. 91, to be furnished with teeth for half of its periphery only, the rack *b* will have an intermittent motion; being at rest during the period of revolution when the part of the wheel *a*, having no teeth, is presented to the rack, but moved forwards when the teeth of the wheel gear with those of the rack *b*. (2.) By making the wheel *a* revolve once in one direction, and once in the

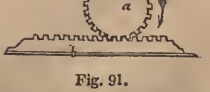

Fig. 91.

opposite, alternately; the rack *b* will have an alternating motion from right to left. (3.) The stamper or weight *c*, fig. 92, will have an intermitting movement given to it by the cambs of the wiper-wheel *a b*; the weight will rise and fall twice during one revolution of the wiper-wheel *a b*.

Fig. 92.

236. When an alternate rising and falling is required *thrice* by only *one* revolution of an axle, an eccentric-wheel is used having three projecting cambs on its circumference; and as each camb comes round, it lifts and lets fall any object presented to it. An example of this apparatus is given in fig. 93. The object required is to work a heavy hammer upon an anvil for beating iron. W is the wheel with the three cambs, and it turns by an axle in upright supports. In turning, each camb, with its rounded or convex side, presses down the end of the handle of the hammer, so as to raise the heavy head H at the opposite end. After pressing down the handle, and escaping, the head of the hammer falls with a heavy blow on the anvil A. There it remains till raised up and let fall by the next camb; and so on.

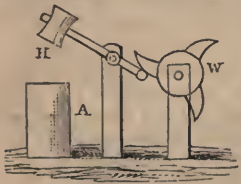

Fig. 93.

237. The lever *a c*, fig. 94, will rise and fall through a space equal to *a b* during the revolution of the heart-shaped wheel or camb, the centre of which is *b*.

Fig. 94.

Fig. 95.

238. An alternate motion from one side to another is given to a drum, or horizontal drum or pulley *a a*, fig. 95, by the

contrivance known as the *mangle-wheel motion*. To the face of the pulley a double circular rack, *d d*, is attached; the axis of the pinion *b*, which gears into this rack, is allowed to traverse in a slot, so that it will, on reaching the end of the outside rack, pass round the teeth of the curved ends, along the slot, and gear with the teeth of the inside rack. By giving a continuous motion to the pinion *b*, it will engage with—say the teeth of the outside rack—thus moving the rack and pulley in the opposite direction; but as soon as the pinion gears with the teeth of the inside rack, the direction of both is the same (see the annular-wheel, fig. 86); and the pulley thus moves in an opposite direction.

239. *To change reciprocating into circular motion.*—(1.) By the crank. In fig. 113, on the chapter on the steam-engine, the reciprocating movement of the piston-rod *d*—the parallelism of which is preserved by the cross-head *e e* sliding between the guides *f f*—is changed into the circular one of the fly-wheel *j*, by the crank *h* fixed to the fly-wheel shaft, and the connecting-rod *g g*. To admit of the movement of the rod *g g* from right to left, and *vice versâ*, it is jointed to the crank-pin at one end, and to the piston-rod cross-head *e e* at the other. (2.) In fig. 116, the reciprocating motion of the piston-rod *a a* and beam *b b*, by the intervention of the connecting-rod *c c* and crank *d*, is changed into the continuous circular motion of the fly-wheel *e e*. (3.) The continuous circular motion of the fly-wheel of a knife-grinder's wheel is produced from the alternate rising and falling of the foot of the operator, acting on the foot-board by the intervention of the connecting-rod and crank. (4.) The sun-and-planet wheel motion was used by Watt to change the reciprocating motion of the piston-rod into the circular one of the fly-wheel. To the end of the connecting-rod a toothed wheel was firmly fixed; this geared with another wheel of the same size, fixed on the fly-wheel shaft; the centres being connected with a jointed link. The connecting-rod, as it rose and fell, carried the wheel at its extremity round the periphery of the wheel fixed on the fly-wheel shaft, and at the same time gave motion to it and the fly-wheel.

240. *To change a circular into a reciprocating motion.*—A very general method of doing this is by the use of the eccentric; the constructive details of which we have shewn in fig. 81.

241. An *eccentric-wheel* is a wheel with an axis not in its centre, but at a point nearer one side than the other. Fig. 96 represents the action of a wheel of this kind. W is the wheel, and A the axis upon which it is fixed. When the axis turns,

the wheel turns with it. As the axis never moves out of its place, the wheel necessarily describes a path of gradual rising and falling in its revolutions. Suppose an object, as T, pressing upon the upper edge of the wheel, so as to accommodate itself to the motion, it is obvious that, by the action of the wheel, this object will be alternately raised and allowed to fall. Or suppose that a rod is hung from a point of the wheel near where T rests, it is similarly obvious that the rod would be raised or depressed according as the wheel turned. Thus a rising and falling motion may be effected by an eccentric-wheel.

Fig. 96.

242. The heart-shaped wheel or eccentric *b*, fig. 94, is another method of producing reciprocating from circular motion; as also the rack and pinion, fig. 91.

243. In some cases, eccentric-wheels are not required to perform entire revolutions on their axes. It is perhaps sufficient for the purpose of the mechanism if they gradually rise to the height of their power, and then, without turning round, gradually descend by retracing their course. An example of this kind of motion is given in the adjoining figure. L is a lower circular wheel turning on a fixed central axle, which axle rests on two supports not drawn in the figure. P is a bar or lever by which the axle is turned. By depressing the lever at P, the wheel turns, and by its teeth propels the semicircular eccentric-wheel above it. The eccentric-wheel, in going forward, is compelled to rise to its full height, which height it has attained when its extremity at F is brought straight above E. In thus ascending, it pushes upwards the beam E, which is attached to it by an axle through E. The beam E consequently pushes up the board M, and presses any material, *m n*, against the topmost board A B. This topmost board is fixed to supports, not drawn in the figure, and neither rises nor falls. By this process of winding up the semicircular eccentric-wheel, the utmost height of pressure of the machine is attained. The lever is then turned by a reverse motion, and the semicircular eccentric-wheel comes to its lowest depression when its extremity at F is brought near to L.

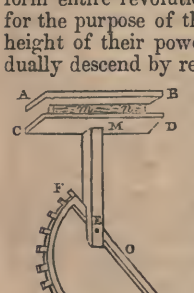

Fig. 97.

244. *To change a reciprocating circular motion into reciprocating rectilineal.*—The well-known parallel motion of Watt is

a familiar exemplification of this movement. Let *e a*, fig. 98, be the beam; to two studs or centres in the direction of its length, two links of equal length are jointed at one end, as *b e*, and at the other to another link *c d*, which is always parallel to the line of centre of *e a*. A lever, *f*, is jointed at *d* at one end, and at the other to a stud on a fixed support *g*. The end of the piston-rod *h* is fixed to a cross-head or bar jointed with the ends of the lever *c b*. On the other side of the beam a similar set of levers are arranged. The piston-rod *h*, in this arrangement, moves in a straight line, while the end of the beam *e a* moves in the arc of a circle.—A continuous circular motion is changed into a reciprocating rectilineal one by the contrivance known as *White's parallel motion*. This is illustrated in fig. 86, and proceeds upon the principle, that if a pinion *b*, of diameter equal to the radius of the annular-wheel *a a*, be made to roll within the fixed annular-wheel, a point *c*, in the pitch circle of the pinion *b*, will describe a right line. If, then, the end of a piston-rod be attached to this point, it will move in a straight line.

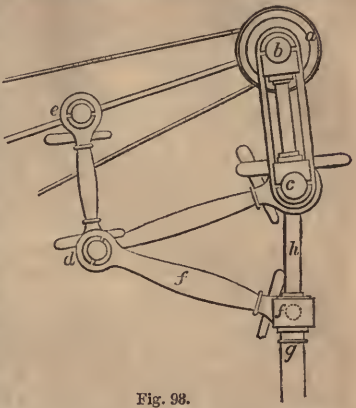

Fig. 98.

ACCUMULATING AND EQUALISING OF POWER.

245. Power is susceptible of *accumulation*—that is, of increasing little by little—and of being expended either gradually or in one or more violent efforts; the efforts being entirely the concentrated amount of the previous accumulation. The apparently wonderful powers displayed through the agency of levers and other simple machines, are all a natural consequence of an accumulation of any degree of force into a small space, by which effects take place that could never have been accomplished by the original force.

246. In consequence of this convenient accumulation of power in machines, plans have been devised for establishing *reservoirs of power*, as they may be called, in connection with moving machinery.

247. A well-known method of accumulating power consists in suspending a heavy body by a chain or strong rope of considerable length—forming what is called by young persons a *swing*. This body may be put in motion by a very small degree of power, and will acquire a vibrating motion like a pendulum. By continuing the impulse as the body returns, it will continually acquire greater and greater force, the arcs through which it moves becoming continually larger, until at last it might be made to overcome almost any obstacle. Upon this principle the battering-rams, or engines for beating down the fortifications of towns in ancient times, were constructed, and the force of their blows was as great as that of a cannon-ball; nevertheless, the power of their blows never could exceed the accumulated power of the impulses given to them in order to produce these blows.

248. The forcible expenditure of accumulated power in the swing apparatus, resembles that which is observable in the case of a person occupying several minutes in bending a spring—that is, accumulating power—and then allowing the spring to unbend itself by one violent effort; which effort is nothing more than the giving out of the accumulated power.

249. A boy taking a race to gain force before making a leap, is another familiar example of accumulating power and expending it instantaneously. The boy is gathering up power at every step he runs, and the force of his leap corresponds exactly with the quantity of momentum he has acquired.

250. In contrivances in the arts, power is sometimes accumulated in order to be given out in the form of a rapid and effective blow. This may be done by means of a horizontal bar or lever, poised on a central axis, and loaded at each end with a heavy ball of lead or iron. After communicating to the machine a sufficient power of rotation, it will proceed with an enormous accumulated energy and momentum, till it expend its force either by friction in turning, or upon some fixed obstacle presented to it.

251. The press used for stamping or taking impressions of coins and similar articles from dies, furnishes one of the best examples of the instantaneous expenditure of accumulated power. A press of this kind is represented in fig. 99. The apparatus is very simple. It consists of a strong upright frame of iron, with a thick screw S suspended from the upper cross-beam, and going through a middle cross-beam. In these two beams the screw works freely. The screw is wrought by a horizontal lever bar poised on a

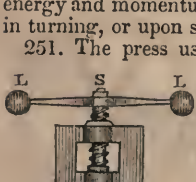

Fig. 99.

central axis, and loaded at each end with a heavy ball L L. The die lies on the point D below, and the blank piece of metal to be struck is laid upon it. If a coin with two sides is to be impressed, another die is fixed upon the point of the screw. The rapid and forcible pulling round of the lever causes the screw to sink, and by a single rapid crush or blow upon the metal against the die or dies, the impression is made. The shock of concussion causes the screw to rebound upwards; and the instant a vacancy is left below, the impressed metal is taken out, and a new piece is inserted. By this simple process, coins, medals, ornamental metal buttons, and similar articles are struck.

252. In most machines, both the moving force and the resistance to be overcome are liable to fluctuations of intensity at different times during the operation of working. For instance, when a man turns a winch or handle of a piece of machinery, he is apt to relax in his efforts for an instant from loss of strength, or from an inability to keep his attention closely and uniformly fixed to the labour he has to perform. These relaxations cause an irregularity of motion in the machinery, which is detrimental to the machine and to the work performed. Other moving forces are liable to similar irregularities.

253. The irregularities in the motion of machinery, from whatever cause they arise, are remedied by giving to each machine a *reservoir of power*, from which force may be given at all times to equalise the motion, according as it may be required. These reservoirs of power are usually in the form of *fly-wheels*.

254. A fly-wheel is generally made of iron, and consists of a heavy rim or circumference, joined to a central axis by cross bars or spokes (fig. 100). In most cases, it is placed in close connection with the first moving force, the effect of which it equalises in its passage to the machine.

Fig. 100.

255. Whatever quantity of power is communicated to a fly-wheel, the fly accumulates it, and gives it forth as may be required, in order to overcome any small variations in the first moving force, or in the working of the machine.

256. The power is communicated to the fly-wheel at its axle, and thence affects the whole fabric. The motion is at first given in a gradual manner, till it becomes steady. If there were no machine to retard the speed, and the impulsive force continued

to be administered, the effects, from centrifugal force, would soon be overpowering.

257. In practice, the friction of the various parts of the machine checks the tendency to over-velocity; and when the machine lags, or tends to work irregularly, the gathered momentum of the fly is expended in preserving regularity.

258. The weight, size, and velocity of fly-wheels, are regulated by the nature and quantity of the power applied, and the nature of the machinery to be put in motion. There is a certain degree of velocity at which the force employed will produce the greatest effect; and it is of importance to keep this circumstance in view in the construction of machines.

REGULATION OF POWER.

259. In some mechanical contrivances, the force which is applied varies in its intensity, while the wheels of the machinery require to be kept at a uniform speed. This is generally the case when the force is communicated from a steel spring, which, after being wound up, is suffered to relax. Fig. 101 is a spring suited for operations of this kind. It is represented in a state of relaxation, and is wound up into a compact form by means of a spindle fixed to its inner extremity.

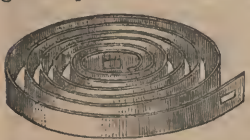

Fig. 101.

260. The coiling of a strip of paper round the finger, and allowing it to unwind itself, is a familiar illustration of the action of a spring of this description.—The force communicated by the relaxing of the spring varies in its intensity. The force is greatest when it begins to relax, and it gradually weakens till its expansive energy is exhausted. To compensate this defect, a very ingenious plan is adopted, and which is put in operation in the apparatus of the common watch.—Fig. 102 represents the apparatus of motion in a watch, somewhat magnified. The spring is confined in a brass cylinder or barrel B. To this barrel the spring is attached by a slit at its outer extremity. The inner extremity of the spring is fixed by a similar slit to the central axis or spindle. F is a brass cone, broad at bottom, and narrow at top, with a path winding spirally round

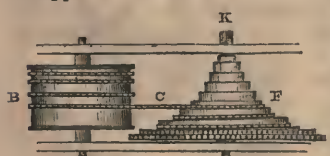

Fig. 102.

it as an inclined plane. This cone is called the *fusee*, and has also a central axis or spindle K, to which it is fixed. To a point on the lower inclined path of the fusee, a small steel chain, C, is attached, and the other extremity of this chain is attached to the top part of the barrel. When the spring is relaxed, the chain is almost altogether round the barrel. To set the apparatus in motion, the watch-key is made to turn the spindle K, by which the chain is drawn from the barrel to the fusee, filling up the inclined path to the summit. The chain, in leaving the barrel, causes it to turn, and consequently to wind up the spring inside. The process of unwinding or relaxing ensues, and now the ingenious plan for regulating the motion is to be remarked. At first, when the force of the spring is greatest, the chain acts upon a small round of the fusee; in other words, it pulls with a small lever, for, as already explained under the head WHEEL AND AXLE, a wheel or round object on an axis is simply a perpetual lever.

261. In proportion as the intensity of the force weakens, and the barrel takes off the chain from the fusee, and winds it about itself, so does the chain act upon a longer lever, or so does it gain a greater lever-advantage, by drawing at a wider part of the cone. Thus the gradual loss of force is counterbalanced by a gradual increase of lever-advantage. (The case resembles that of a strong man working with a short lever, and a weak man working with a long lever; both are equal in effect in balancing any resistance.) The wheelwork of the watch is moved by teeth on the lower circumference of the cone.

262. The steam-engine governor is another method of regulating the speed of a machine. A description of this will be hereafter given.

ENGAGING AND DISENGAGING MACHINERY.

263. In many cases, particularly where numerous machines are propelled by a common power, it is important to possess the means of stopping any one of them at pleasure, and of restoring its motion, without interfering with the rest. To produce this effect, various plans are pursued.

264. The most common and simplest device used in cases of motion by belts, consists in having a *fast* and *loose pulley*. Alongside of the pulley whose axle moves the machinery, and on which the belt works, there is a pulley or wheel loose on its axle, called the loose-pulley, from its inoperative character. When the machine is to be stopped, the belt is shifted from the fast or active pulley to this loose-pulley, which it turns without producing any effect on the machinery. Motion is

restored to the machine by shifting the belt back to the fast-pulley. A long rod, with a clutch at its extremity, and easily affected by the hand of the workman, turns the belt off or on at a moment's notice.

265. Another method of engaging and disengaging machines is by the use of the sliding-clutch, or coupling. Let *a*, fig.

Fig. 103.

103, be the driven shaft, or that which takes the motion to the machine; and *b* the driving-shaft. To *a* a coupling-box is fixed, with projections and indentations on its face; a clutch, with corresponding indentations, &c., is capable of sliding along the shaft *b*, on two feathers or ribs projecting from its surface, but which revolves with the shaft. This clutch is moved to and from the fixed clutch *d* by a lever, the fork of which embraces the journal *g* of the clutch *d g*. When the clutch *d*, which is carried round by the shaft *b*, is moved along the feathers, so that its projections go into the indentations of the clutch *g*, and the two become locked together, the shaft *a* partakes of the motion of *b*. The two are kept in contact by the lever which moves *g* being placed against a stud; by releasing it from this stud, the lever can be moved, and the clutch *g* thrown out of connection with *d*, and the motion of *a* thus stopped.

OBSTACLES TO MOTION.

266. Moving bodies, as machines and wheel-carriages, are less or more retarded in their velocity by friction, and the resistance of the atmosphere, while vessels moving on water are retarded by the resistance both of the atmosphere and of the liquid in which they are buoyant.

FRICTION.

267. Friction is an effect of the action of rubbing of bodies one upon another.

268. This effect is produced by inequalities of surface. No such thing is found as perfect smoothness of surface in bodies. In every case there is, to a lesser or greater extent, a roughness or unevenness of the parts of the surface, arising from

peculiar texture, porosity, and other causes; and therefore when two surfaces come together, the prominent parts of the one fall into the hollow parts of the other. This tends to prevent or retard motion. In dragging the one body over the other, an exertion must be used to lift the prominences over the parts which oppose them, and this exertion is similar to that of lifting or drawing of bodies up inclined planes, or over upright protuberances. The effect so caused is called *friction*.

269. Friction acts as a retarding influence in the action of all mechanical contrivances, and a due allowance must in every case be made for it. In many instances it destroys more than a half of the power employed, and seldom destroys less than a third. However small it may be, it sooner or later causes the wearing down and destruction of mechanism, and therefore forms an insurmountable obstacle to the lasting duration of bodies and the perpetuity of motion.

270. The action in overcoming friction being of the nature of lifting or drawing of bodies up inclined planes, gravity is permitted to have an effect in the drawing of bodies upon horizontal planes not perfectly smooth. Thus *weight* forms an important element in calculating the probable amount of friction of a body.

271. Friction is found to depend on the following circumstances:—1st, The degree of roughness of the surfaces. 2d, The weight of the body to be moved. 3d, The extent of surfaces in certain bodies presented to the action of friction. 4th, The nature of the bodies. 5th, The degree of velocity of the motion. 6th, The manner of the motion.

272. *Roughness.*—It is of the utmost importance to smooth the surfaces. An apparently insignificant piece of matter, or even particles of dust, will greatly retard the motion of a body. But there is a limit beyond which it would be imprudent to smooth the surfaces of bodies having a close texture. If the surfaces be highly polished and levelled, the bodies will adhere by the effect of attraction of cohesion, even when the atmospheric air is not entirely expelled from between them, and more forcibly when the air is completely expelled. Practically, roads, railways, and similar bodies cannot be made too smooth.

273. *Weight.*—Friction from weight differs in different bodies, and depends on concurrent circumstances, as nature of surface, and so forth. Friction always increases in exact proportion as the weight increases, when all other circumstances remain the same. Any moving part of machinery, therefore, should be made as light as possible, consistent with strength and durability.

274. *Extent of Surfaces.*—Rough bodies are more easily drawn along when their surface of contact is narrow than when they are broad. For example, it is easier to draw two narrow brushes across each other than two broad ones of the same weight. Friction may therefore be diminished in rough bodies by lessening the extent of surfaces in contact. But there is a limit to this diminution. If the moving surface be very thin, and the other surface soft, the thin surface will plough a groove in the soft one, and thus the friction will be increased, and the machine injured. In the case of smooth hard bodies, extent of surface makes little difference in the friction.

275. *Nature of Bodies.*—It is a remarkable truth, that two bodies which are of the same nature, or homogeneous, produce greater friction in movement than bodies which are different in their nature, or heterogeneous. This arises from the natural cohesiveness of particles of the same material. Thus, iron working against iron, steel against steel, or brass against brass, causes in each case greater friction and wearing of parts than when iron or steel is made to work against brass. This circumstance is always attended to in the construction of machinery. Frequently, a small piece of leather is adjusted round an axle to prevent the metals from coming in contact.

276. *Degree of Velocity.*—Friction is a uniformly retarding force, except in the case of small velocities, when it is greater in proportion. The reason of its being greater in small velocities is, that in these cases time is allowed for the prominences of the moving body to sink deeply into the hollows of the surface on which it is moving, which has a retarding effect.

277. *Manner of the Motion.*—The least advantageous manner in which one body can be moved upon another, is to cause it to slide or drag. The most advantageous manner is to cause it to roll or turn. The causing of a body to roll instead of to slide, is one of the chief means of diminishing friction. The opposition presented by inequalities of surface to a rolling wheel is overcome with ease, in proportion to the extent of diameter of the wheel. On a perfectly horizontal plane, the friction of wheels on the plane is very inconsiderable; the chief seat of friction in such cases being in the axles working in their sockets.

278. Various plans have been tried to modify the friction of wheels in their sockets. One remedy consists in constantly keeping up a fresh lubrication from small reservoirs of oil placed in the axles or gudgeons, and which supply the deficiency as it occurs. A more effectual plan consists in sur-

rounding the inner sides of the gudgeons with small wheels, upon the rims of which wheels the axle works in turning. These *friction-wheels*, as they are called, save the axle from rubbing on the inner surface of the gudgeons, and transfer the friction to their own small axles.

279. Friction is greatly diminished by lubricating the rubbing surfaces with an oily or greasy substance, which substance forms a medium of minute elastic particles betwixt the bodies, and so prevents the tendency to grind or wear down the surfaces. Water, or any similar fluid, will also act as a medium to prevent friction; but the effects are only temporary, and would frequently be injurious, as the substance speedily evaporates, and would corrode metals. Practically, fine pure oil is found to be the best unguent for machinery.

280. One of the first considerations on the part of contrivers of mechanism, should be how to provide for and diminish the effects of friction in their machines. For want of forethought on this important point, thousands of ingenious schemes, which seemed perfect in the form of models and drawings on paper, have been completely frustrated when attempted to be brought into use.

USES OF FRICTION.

281. Whatever may be the retarding and frequently inconvenient effects of friction in reference to the action of mechanism, it is certain that friction is indispensable in the economy of both nature and art, and serves as an essential auxiliary to gravitation. It is a property which is frequently necessary in order to allow one kind of matter to possess a hold upon another without actual cohesion. We walk and maintain our erect posture by means of gravitation and action and reaction—in other words, we are held to the earth by gravitation, and our pressure with our feet exemplifies action and reaction—but if there was no such property as friction, we should either stick to the earth by attraction of cohesion, or slide along it as upon the smoothest ice. In order to keep our feet from sliding when on ice, if we received any impulse, we either tie rough substances on our shoes, or scatter ashes in our path; and thus we receive the benefit of friction. It is by friction that rains wear down hills, and that rivers wear away their banks, by which ceaseless process the external configuration of the globe is constantly undergoing a change. The operations in art of washing, cleaning, scouring, sharpening, polishing, cutting, bruising, beating, and so forth, are all effected less or more by friction. The hold which one fibrous substance has on another, or mutual friction, permits the operations of weaving cloth,

twisting ropes and threads, and the tying of one body to another. Thus friction is of universal service; and the only known instances in nature in which it is not required, and therefore not present, are the movements of the heavenly bodies, which, so far as has been determined, revolve in a vacuum, and are consequently not impeded in their motions.

RESISTANCE OF AIR AND WATER.

282. Atmospheric air and water are fluids of different densities, but both present an obstacle to the motion of solid bodies through them.

283. There is a rule in respect to the resistance presented in moderate velocities which applies both to air and water. It is, that THE RESISTANCE IS PROPORTIONAL TO THE SQUARE OF THE VELOCITY. For example, a velocity of twenty miles an hour causes a resistance four times greater than a velocity of ten miles an hour, for the square of twenty (which is 20 times 20, or 400) is four times the square of ten (which is 10 times 10, or 100). Thus, by increasing the velocity of bodies through the air or water, we must increase the power in a greater proportion, in order to compensate the loss caused by resistance.

284. Although the above rule is nearly correct for moderate velocities, it deviates considerably from what is observable in the case of great velocities, such as that of a cannon-ball. When the velocity is upwards of 1000 feet per second through the air, the quick passage of the body is believed to cause a partial vacuum behind it, which causes an additional resistance to its motion.

285. Resistance to motion in fluids is greatly modified also by the form of the moving body. The form that gives least resistance is nearly that of a parabola, or a form somewhat resembling the breast of a duck, the head of a fish, or the rounded bow of a vessel, sharpened to cleave the fluid through which the body passes. The body should also taper backwards, like the body of a fish.

MOVING FORCES.

286. The sources of power for moving machinery are various, and are employed according to circumstances. Men and animals, water, wind, and steam, are the principal sources, or, as they are called, *agents* of force. Men and animals operate by muscular energy; water acts by its momentum and gravity;

wind by its pressure; and steam by the expansive energy of heat. There are also other agents of power in nature; such as magnetism, galvanism, electricity, and capillary attraction; but these have hitherto produced motion only on a limited scale.

HUMAN LABOUR.

287. The muscular energy of men forms the most insufficient or the weakest of all the prime moving forces. Human labour is very limited in its compass, and is the least to be depended on for regularity. The power exerted by one man is comparatively small, and it is both inconvenient and expensive to cause a large number of individuals to unite their powers in a continued or concerted effort.

288. The power of a man to produce motion in a machine, weight, or resisting body, varies according to the mode in which he applies his force, and the number of muscles which are brought into action. In the operation of turning a winch or handle of a wheel, a man's power changes in every part of the circle which the handle describes. His power is greatest when he pulls the handle upward from the height of his knees, next greatest when he pushes it down on the opposite side, though here the power cannot exceed the weight of his body, and is therefore less than can be exerted in pulling upward. His power is weakest when at the top and bottom of the circle, where the handle is pushed or drawn almost horizontally.

289. A man can exert the greatest active strength when he is at rest in his person (that is, not walking), and when he pulls or lifts a body upwards from his feet, because the strong muscles of his back, as well as those of his arms and legs, are then brought advantageously into action, and the bones are favourably situated by the fulcra of the levers being near to the resistance. Hence the action of rowing, or pulling oars, is one of the most advantageous modes of muscular exertion. In that operation the whole frame exerts itself in the most favourable manner; and no method which has been devised for propelling boats by the labour of men has hitherto superseded it.

290. It is usual, in estimating the amount of power which can be exerted by animals, to reckon it by the weight which the animal can lift in a given length of time to a given height. By this standard, it is computed that a man of ordinary strength can raise a weight of 10 pounds to the height of 10 feet once in a second, and continue this labour for 10 hours in the day. This is supposing him to use his force under com-

mon mechanical advantages, and without any deduction from friction.

291. All such estimates as this, however, are exceedingly illusive. The ability for exercising power varies in different countries, and depends greatly on exercise and diet; therefore no *practically* useful calculations can be made regarding it.

292. Human strength, as has been said, can be exerted with greatest effect in lifting from the ground, and pulling as with an oar. But this species of action produces exhaustion; hence the advantage is neutralised by a certain disadvantage. The way in which the greatest effect can be produced by human labour, with a moderate degree of fatigue, is simply to allow the weight or gravity of the person to work. For example, let a man walk up a ladder to a certain height, and then stepping into a bucket which is attached to a cord and pulley, permit himself to sink with the bucket to the ground, drawing up a load at the other end of the cord. Whatever be his weight, he will be able to raise at each descent a load nearly equal to it; and therefore by such a plan, he would, in the course of a day, raise a great deal more weight of materials to the top of a house, than by the common process of carrying up a mass of matter in his hands or on his shoulders.

293. In giving effect to the gravity of the person, no exertion is used; and the only source of fatigue is that of walking up an inclined plane to attain a due elevation. According to the principle defined in paragraph 134, the expenditure of exertion in ascending inclined planes is not according to the degree of inclination, but according to the elevation reached. This is agreeable to the rule of mechanics mentioned in paragraph 17; namely, that a small force exerted for a long period of time is equivalent to a great force exerted for a short period of time. Thus, nearly the same degree of animal fatigue is incurred by reaching the same elevation in the same time, whatever be the inclination of the ascent.

294. In walking on a perfectly horizontal plane, the gravity of the person, in ordinary cases, is not felt; for the fabric of the body is so nicely balanced, and the weight so generally borne by the different parts, that we are hardly conscious of the exertion. When we try to ascend a hill, we begin to feel that our gravity retards, and consequently fatigues us, for we are pulling against the force of terrestrial attraction. But when we commence descending a hill, we feel that we are greatly assisted by our gravity—that is, we are allowing attraction to pull us. We are also assisted in descending by an acquired momentum in our person.

295. The moving power given to machinery by the mere

gravity of the person is seldom used, except in the case of involuntary labour at the tread-mill. A tread-mill is a large broad wheel with steps all round on its circumference, and on which steps men are compelled to ascend, holding on by a fixed bar or rail in front. The weight of the men turns the wheel, which, by turning an axle, gives motion, if necessary, to certain machinery. The tread-mill thus forms a revolving or endless stair. Fig. 104 represents one of these machines in operation. A is the axle, S are the steps, and P is a fixed platform in front of them.

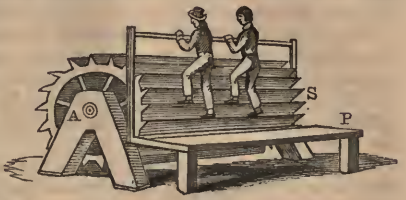

Fig. 104.

296. It is evidently disadvantageous to employ human labour as a moving power, except in cases in which the force required is so small as not to require further aid, or where skill as well as muscular energy is necessary. The human being has been designed for executing higher duties than those which can be adequately performed by the lower animals, and by the agency of inanimate forces.

297. The power of the ass is sometimes employed as a moving force in operations not requiring great labour, and on a principle similar to that of the tread-mill. At Carisbrook Castle, in the Isle of Wight, an ass was lately employed to move a machine acting like a windlass for drawing water from an exceedingly deep well. The animal acted entirely by giving effect to its weight, as represented in fig. 105.

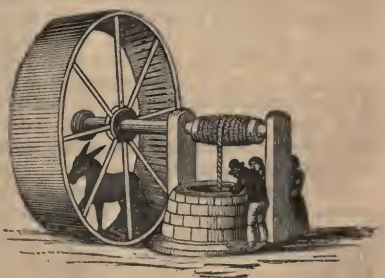
Fig. 105.

HORSE'S POWER—DRAUGHT.

298. Horses and oxen are used, in all countries where they exist, as agents of force. Horses are more valuable for this

purpose than oxen, because they are generally more tractable, and otherwise better suited for the labour. Oxen are used only for draught.

299. A horse employs two forces in drawing—the force of his muscular energy exerted against the resistance of his hind legs and feet, and the force of his weight or gravity. Power of draught is estimated according to the constitutional strength, height of breast from the hind feet, and weight of the animal.

300. The force of a horse diminishes as his speed increases beyond a certain limit. If the load that he can pull, when moving at the rate of two miles an hour, is represented by 100, that at three miles an hour will be 81—at four miles an hour, 64—at five miles an hour, 49—and at six miles an hour, 36.* In this way the draught of a horse continues to diminish, till he attains his greatest speed, when he can barely carry his own weight.

301. A horse exerts his power most advantageously when walking at the rate of about four miles an hour. This advantageous rate of speed, however, does not apply in the case of short efforts. In these, a rapid motion, to get at once over the difficulty, is most advantageous for the muscular energy.

302. There are various estimates of a horse's power, but that of James Watt is generally adopted as the standard. The measure of a horse's power, according to Mr Watt, is, that he can raise a weight of 33,000 pounds (for instance, drawing it over a pulley) to a height of one foot in a minute.

303. In comparing the strength of horses with that of men, it is estimated that the force of one horse is equal to that of five men. But this estimate is liable to certain important exceptions. Much depends on the manner in which the exertion takes place.

304. Any body moving forward on a smooth horizontal plane, can be drawn with the least possible force when the line of draught is straight in a horizontal line from the power to the point of resistance. But a horse, in drawing, can use his weight and muscular energy with greatest advantage when the line of draught inclines from the load upward to his breast. Thus the convenience of the horse must always be consulted in practical operations.

305. A horse also can pull a wheeled carriage with greater advantage when the wheels are large than when they are

* These proportions are given by Professor Leslie, and are confirmed by the observations of other experimentalists.

small, because large wheels get most easily over obstacles lying before them. This is an evident truth, but it can be proved by an appeal to the principle of the lever.

306. The operation of drawing a wheeled vehicle presents an example of lever action of a peculiar kind. The load of the vehicle, or the *weight*, presses on the nave or axle of the wheel, and the direction of its action thence passes down in a straight line to the plane on which the vehicle rests. The direction of the power is a line from the moving agent to the axle. If the plane be perfectly smooth, the *fulcrum* is identified with the point on which the weight presses on the ground. If any obstacle be placed before the wheel, then that obstacle, at the instant of contact, becomes the *fulcrum*.

307. Fig. 106 represents a wheel, with an obstacle, which we may suppose to be a stone, lying before it. The line of draught P A is the direction of the power. A horse may be supposed to be pulling at P. The line A W is the direction of the weight. F is the obstacle, or fulcrum, upon which the power has to act. A line from A to F may represent the lever, having the fulcrum F at one extremity, and the power and weight applied to the other extremity A. The apparatus is thus a lever of oblique action with a single arm. According to the rules laid down for estimating the power of bent levers, the arm of power is an ideal line drawn at right angles from the line A P to F, and the arm of weight an ideal line drawn at right angles from the line A W to F. The mechanical advantage is calculated from these two ideal lines. By increasing the diameter of the wheel, these ideal lines increase, but that of the power increases in the greatest proportion, and hence the advantage of increasing the diameter of wheels.

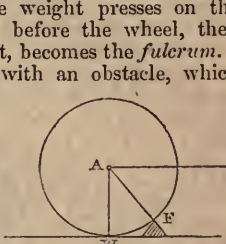

Fig. 106.

308. It is customary to place small wheels before large ones in four-wheeled carriages. This is done only for the sake of convenience in turning the vehicle; if the front wheels were made as large as the hind ones, the carriage would be more easily drawn.

309. In yoking several horses, one before the other, to ploughs or wheeled carriages, it is of importance to cause the line of draught of all the horses to proceed in a straight line to the point of resistance, or as nearly so as is convenient. The resistance of the plough is in the sock or cutting part in the earth, and the resistance of the load in wheeled carriages is at the axles. The distance of the animals from the machine

they are drawing is of little consequence, provided each horse is able to exert his force directly in a line to the resistance.

310. Horses draw with best effect when they are yoked singly or abreast. In yoking them one before the other, a portion of their force is generally expended uselessly, if not mischievously, in hampering each other. When a horse draws a four-wheeled carriage, the line of his draught should go to a point between the two axles, and come over the front axle. The same rule holds with two or more horses in four-wheeled vehicles.

311. Wheels have least friction where they are narrow in the rim; but this is supposing the road to be hard and smooth. In cases of great weights, and when the roads are not very smooth or hard, broad wheels are the best for both safety and draught. Wheels which are perfectly straight or upright are pulled with less exertion than wheels which are of a *dished* form—that is, with the spokes sloping to the rim; but the dished form is of use in widening the base, and preventing overturning; it is also particularly useful where the road is inclined to one side, as the spokes of the lower wheel, which then support more than half the weight, are more nearly in a vertical direction, and therefore resist the pressure with greatest effect; so that when the load is thus increased upon them, their resisting power is at the same time increased.

312. When the load is suspended on springs, the shocks caused by friction in movement are lessened—that is, the force of the concussions is spent upon the elasticity of the spring, a circumstance of great convenience to passengers in carriages. The elasticity also preserves equability of weight to the horse. At every jolt over a protuberance, without springs, the load receives a momentum in descending, which, on being checked, gives a shock to the animal in the shafts; whereas in using springs, the weight has always a comparatively equal pressure.

313. Horses communicate moving power to machinery by being yoked to a horizontally-turning beam or wheel, and walking in a circle. The motion of the beam or wheel, by acting on a pinion and shaft, moves the machinery. Many mills are turned in this manner. To give full advantage to the capacity of the horse, the circle should not be less than from thirty to forty feet in diameter.

314. Fig. 107 represents the action of horse-power upon a mill. U is an upright axle working on pivots, from which axle a beam B B is projected, and into which two horses H H are yoked. W is a horizontally-moving wheel on the axle,

which wheel turns a trundle T fixed to the shaft S. The turning of the shaft moves the machinery.

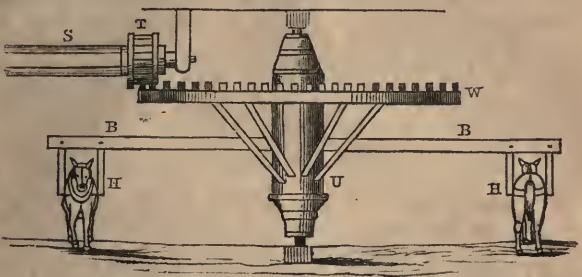

Fig. 107.

315. The same principle applies with respect to the employment of horses and other animals, as agents of force, as that which applies to human labour (par. 296). An animal is only employed advantageously when he is caused to do work which could not be as conveniently executed by inanimate forces. In all cases in which inanimate forces can be conveniently substituted for animal power, the application of the animal is not legitimate, because only its weight and muscular energy are brought into operation, and its sagacity, which is frequently a valuable part of it, lies unemployed.

WATER-POWER.

316. Water acts as a first mover by the force of its gravity or weight; and also in some cases by its momentum or impulsive power. It is applied by causing it to fall or flow upon the outer part of a wheel, which turns with the force.

317. Water-power, if to be had in a sufficient quantity, is preferred to all other powers, in consequence of its simplicity of action, extraordinary cheapness, and steadiness.

318. The mode of applying water-power to a wheel depends on the extent of the fall, or the height of the stream at the point where it can be properly applied. It is of importance to have as great an extent of fall as possible; but at the same time a certain declivity must be left below the mill, in order to allow the water to flow freely away, and not obstruct the wheel in its motion.

319. Two chief kinds of water-wheels are used, according to the extent of the fall and the nature of the stream. When

the water cannot be made to approach the wheel higher than a point opposite the middle of the wheel, a *breast* or *middle-shot* wheel is used. The water is brought by an artificial channel, and permitted to flow or fall into buckets fixed in the outer circumference of the wheel. The weight of the water in the buckets presses down the wheel, and causes it to turn. When the buckets come to the bottom in revolving, they let the water flow from them, and go up empty on the other side, ready to be again filled and pressed downwards.

320. Fig. 108 represents the action of a breast water-wheel.

Fig. 108.

W is the water flowing from a channel L into the buckets B B, which are supposed to be seen through the sides of the rim; these buckets are emptied on coming down to F, and the water flows away in the channel C. From W to F is reckoned the height of the fall. The axle of the wheel in this case turns the machinery; but sometimes the wheel has teeth round its circumference, which, working on a pinion, communicates the motion to the machinery.

321. When the fall is considerable, or when the water can be made to approach by a channel on a level with the top of the wheel, an *overshot*-wheel is used, such as is shown in the accompanying sketch (fig. 109). The water is allowed to fall into the buckets at the top, so as to act much more advantageously than if it fell from a less elevation.

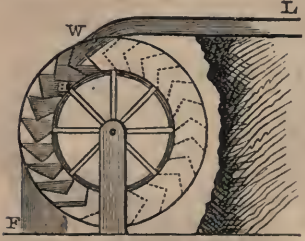

Fig. 109.

322. Where the fall is small, and the flow of water abundant, an *undershot*-wheel is the kind usually employed. In this case the circumference is mounted with float-boards instead of buckets, and those immersed in the stream are moved forwards; that is, the wheel is turned round by the mere impulsive force of the current. This is the least effective of vertical water-wheels—never producing, even when the float-boards are curved to receive the full impact of the current, so much as one-half the absolute maximum of the fall; whereas in a

well-constructed overshot, fully three-fourths of the absolute maximum is frequently obtained.

323. Besides these, attempts have been made to construct water-wheels moving in a horizontal direction. This has been most successfully accomplished by Fourneyron, in what are known by the name of *turbines*, where the water, after being conducted by an arrangement of cast-iron tube and reservoir, is made to impinge in a horizontal direction against the curved float-boards of a horizontal wheel, moving round a vertical axis. Turbines are of recent invention, and are particularly useful for high falls, which do not admit of the application of vertical wheels: they yield about three-fourths of the absolute maximum of the fall.

324. Barker's or Segner's wheel, which depends upon principles to be noticed under the head of HYDROSTATICS, has also been applied as a moving force, but hitherto with very little effect.

325. Water-power, acting either by breast, overshot, or turbine wheels, is a much more effective and steady agent of moving force than wind. Windmills are used only in cases in which perfect regularity and constancy of motion are not required, or where water cannot be obtained at a sufficient height to form a fall.

STEAM-POWER AND THE STEAM-ENGINE.

326. Water boils at 212 degrees of Fahrenheit's thermometer, under the common atmospheric pressure; and the application of fire, after it reaches the boiling-point, causes it to fly off in the form of vapour or steam.*

327. A cubic inch of water produces almost exactly a cubic foot of steam, or 1728 cubic inches. In its expansion, therefore, it exerts enormous force, and this circumstance has rendered it valuable as a source of power.

328. Steam is applied to machinery by means of a boiler and an apparatus called the *steam-engine*. Steam-engines are of different constructions, and improvements and simplifications are continually taking place in their character and mode of working. The power exerted by steam-engines is estimated according to the horse-powers they are equal to, and which there are certain rules for calculating.

329. Steam-engines, as generally employed, are divided into two classes—*high-pressure* and *low-pressure*. The mechanical arrangements of the former are much less complicated than

* See LAWS OF MATTER AND MOTION, in which the subject of heat in application to water is fully treated of.

those of the latter. The distinction between the two may be

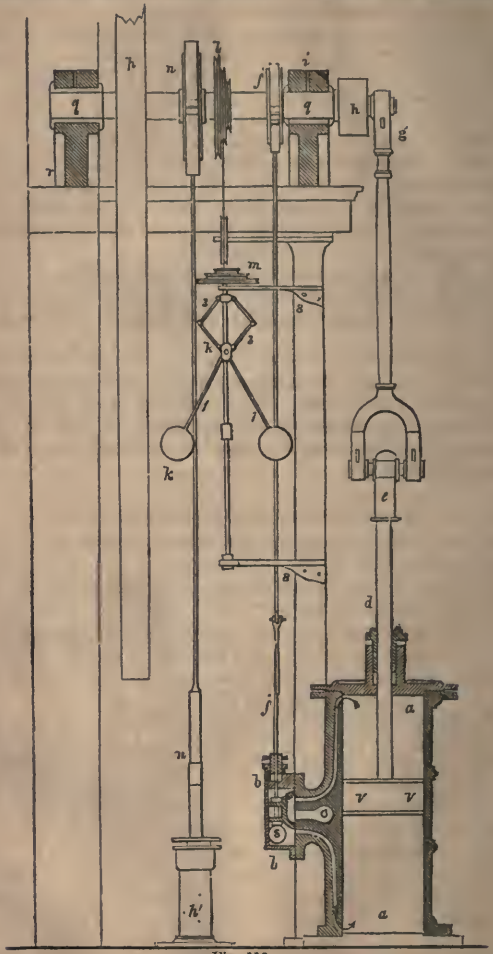

Fig. 110.

briefly stated. In the low-pressure engine, the steam employed

to work the engine is passed from the prime receiver into a vessel called the *condenser;* and coming in contact with a jet of cold water, it is condensed, and a vacuum formed on one side of the piston. As this vacuum is, to some extent, a source of power—the piston being sucked, as it were, up or down the cylinder—the steam necessarily is not of such great pressure as is the case where the piston has to be forced against the pressure of the atmosphere. In the high-pressure steam-engine, the steam presses the piston up and down against the atmospheric pressure. After working the piston, the steam passes at once into the atmosphere. The low-pressure is also called the *condensing*, and the high-pressure the *non-condensing* steam-engine.

330. The varieties of high-pressure engines are very numerous: we give illustrations of a form known as the *crank overhead*. This will enable the reader to form a pretty fair estimate of the usual mechanical arrangements of a non-condensing steam-engine.

331. Fig. 110, page 90, is a vertical section of the form alluded to in last paragraph. The steam is admitted from the boiler to the steam or valve chest *b b*; in this chest the valve works, sliding steam tight against the valve face of the cylinder *a a*. There are three steam-ports—one of these leading to the bottom, the other to the top of the cylinder; the third, marked *o* in the drawing, leads to the exhaust-pipe (*c*, fig. 113). The valve covers two of these ports at the same time, one of which is always the exhaust-port. When the valve *a* covers the upper steam-port *c*, fig. 111, and the exhaust-port *b*, the steam rushes from the space of the cylinder above the piston, down the port *c*, and through *b* to the atmosphere; at the same time the steam is rushing from the steam-chest, down the port *d*, to the under side of the piston *v v*, fig. 110, which it presses upwards. On the piston *v v* reaching the top of the cylinder *a a*, fig. 110, the valve is changed to the position of the diagram to the left in fig. 111. The valve *a'* covers the exhaust-port *b'*, and the lower steam-port *d*; the steam is rushing from the space below the piston *v v*, through the port *d*, and to the atmosphere through the exhaust *b'*. Fig. 112 shews

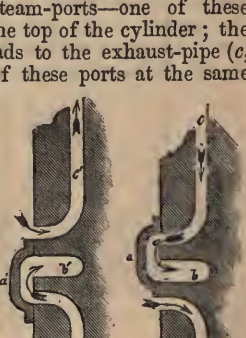

Fig. 111.

a front-view of the face against which the valve works; *c* the upper, *d* the lower steam-port; *b* the exhaust-port.—The movement of the valve up and down, is produced by the revolution of the eccentric and eccentric-rod *j j* (fig. 110), the play of the valve being double the distance of the working-centre of the eccentric from its true centre. The revolution of the crank-shaft *q q* is effected by the crank *h*, and connecting-rod *g*; this latter being fastened to the end of the piston-rod by what is called a *piston cross-head*. The parallelism of the piston is preserved during its reciprocation by the cross-head *e e*, fig. 113, sliding between two parallel guides *f f*, bolted to the upright framing which supports the crank and fly-wheel shaft. The crank-shaft is supported on bearings *q q*, *r*, fig. 110.—The water is supplied to the boiler by the force-pump *k'*, which is worked by the rod and eccentric *n n*.—The supply of steam is regulated by the governor *k k*. This is supported by two brackets 8 8, bolted to the upright framing. A three-motion pulley, *l*, is fixed on the fly-wheel shaft, and a corresponding pulley on the upper termination of the governor-spindle. As the planes of motion of these pulleys are in opposite directions, a guide-pulley, *m*, is used to take the motion of the pulley on the shaft to that of the governor. As the governor is made to rotate rapidly, the balls *k*, by virtue of the centrifugal force, fly outwards, extending the arms or levers 1 1, and depressing those marked 3 3. Those are fixed by movable joints to a brass bush, which slides up and down on the spindle. The periphery of this bush—which is provided with projecting ruffs or collars—is embraced by the fork of a lever, which is connected with the throttle-valve fixed to the steam-pipe *b*, fig. 113. The valve is thus closed—the admission of steam to the cylinder is lessened—the velocity of the engine is diminished—the governor rotates more slowly—the balls fall, lowering the arms 1 1, and raising the arms 3 3; and thus again opening the throttle-valve, allows the steam to enter the cylinder.

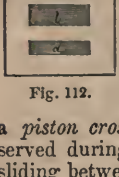

Fig. 112.

332. Fig. 113, page 93, is a front-elevation of the engine of which we have given the section. A A, the upright framing, firmly secured to the sole-plate by bolts and nuts; *a a*, the cylinder; *d*, the piston-rod; *e e*, the piston cross-head; *f f*, the piston-guides; *g g*, the connecting-rod; *h*, the crank; *i i*, the pedestal; *j*, the fly-wheel shaft.

333. In fig. 77 we gave a section of the crank of this engine, with the crank-pin *d*; in figs. 78, 79, and 80, the details

of the connecting-rod end nearest crank; and in fig. 81,

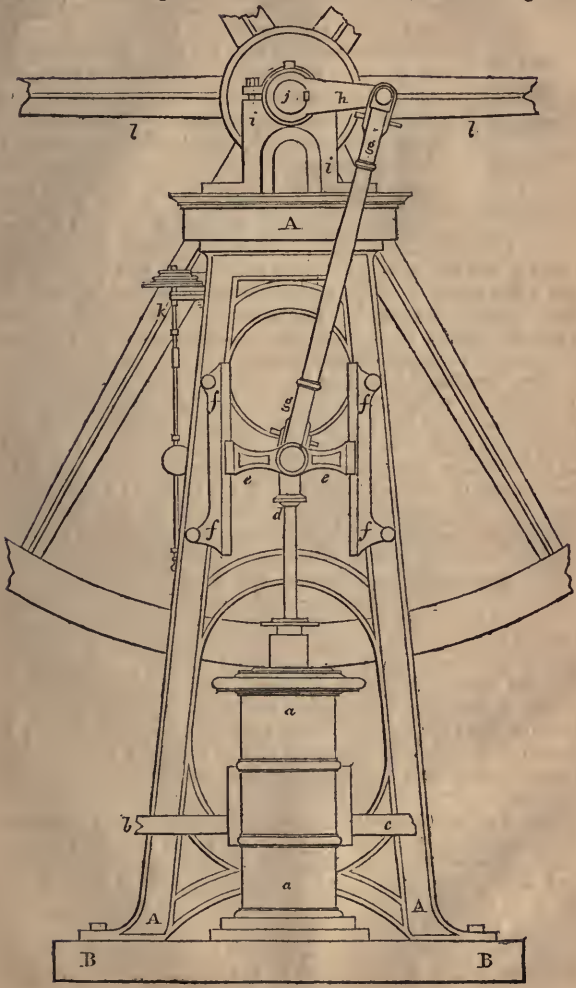

Fig. 113.

details of the steam-valve eccentric. In fig. 114, we shew the method of attaching the eccentric pump-rod *n n*, fig. 110, to the pump-plunger; *a a* is the upper part of the pump-plunger; it is forked at its termination, the two forks *b b* being circular, as shewn at *a b'*. Holes are bored in these forks, through which the pin *e* passes, and which is secured by the cottar or key, *f*, being driven through the key-seat made at the end of *e*. Previous to inserting and securing the pin *e*, the end *c c'* of the eccentric-rod is inserted between the forks *b b*, so as to make the aperture made in it, as *d*, coincide with the apertures in *b b*; the pin *e* is then driven in, and secures them together.

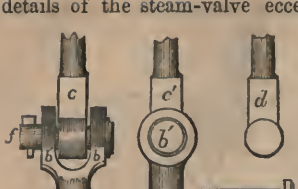

Fig. 114.

334. The piston *v v*, fig. 110, is made to move steam tight, or nearly so, by being fitted with metallic packing. Formerly, the periphery of the piston was wrapped tightly round with hemp, and kept well lubricated. This, however, was found to be so defective, that metallic pistons were introduced, and are now almost universally adopted. Fig. 115 shews a half-section of a form introduced by Mr Wilson, of the Low Moor Ironworks, Yorkshire, and which will sufficiently explain the principle of the metallic pistons in their various forms. *a a* is the aperture in which the piston-rod is fixed; a ledge or recess *b b* is made all round the piston; two rings are placed on this ledge; these rings are cut into segments, and so placed that the lines of division of one ring are placed against the solid parts of the other. Angular recesses are made at certain parts in these rings; into these, angular pieces are pressed by helical springs. The segments of the rings *b b* are thus kept pressed out against the periphery of the inside of cylinder.

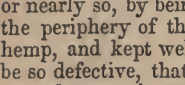

Fig. 115.

335. We now proceed to illustrate the general arrangements of the condensing steam-engine. The usual form in which this is met with is the *beam*. Fig. 116 gives a section of this form.—The steam, after working the piston *a* alternately up and down, passes into the condenser *f*, where it is condensed by a jet of cold water: this jet is regulated by the valve and handle, *b'*. The condensed steam and water is pumped out of *f* by the air-pump *g*, and delivered to the hot-water cistern *h*; from which it is pumped to the boiler by the hot-water

pump *j*. The cold water to supply the jet for condensing, and the cistern in which the condenser *f* and air-pump *g* are

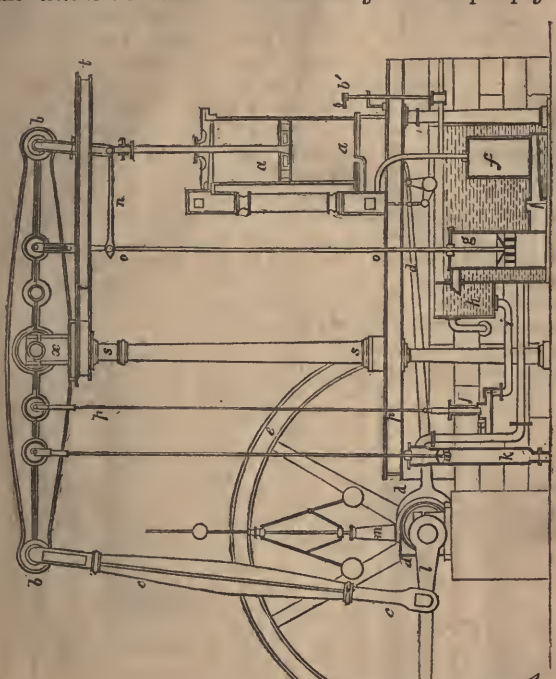

Fig. 116.

immersed, is supplied by the cold-water pump *k*. The framing which supports the main centre *x*, is called the *entablature*. In some engines, this is supported by a series of pillars; in the present example, by one central pillar *s s*, the end of the entablature being supported by the wall; *a* is the piston-rod; *n*, the parallel motion; *b b*, the working or sway beam; *c c*, the connecting-rod; *d d*, the eccentric and rod for working the valves; *l*, the crank; *e e*, the fly-wheel; *m*, the governor; *o o*, the air-pump rod; *p p*, the hot-water pump rod.

336. The steam is admitted to the cylinder by a different

arrangement of valve from that adopted in high-pressure cylinders. The valves for condensing-engines are generally of two kinds—the *long D valve*, and the *short D*. We illustrate the form and mode of using the first of these. The valve consists of a long hollow tube, the section of which is somewhat semicircular, as in fig. 118: a vertical section from top to bottom is shewn in fig. 118, at *a a*; the hollow passage *b b* extends from one end to the other. At top and bottom, flat faces, as *a*, fig. 117, and *c e*, figs. 118, 119, are left. These are accurately ground, and made flat and smooth; and work up against faces on the valve casing of the cylinder. The back of the valve is kept tight by packing at *c*, fig. 117, and works up against the back of the steam-chest or valve casing. A rod, *b' b*, is fixed to the valve, by which it is moved up and down. Fig. 118 shews the steam distribution when the piston is at the bottom of the cylinder. The steam enters through the throttle-valve *g*, passes down the space in front of the valve, and through the lower port *e*, to the under side of the piston. The steam from the upper side of the piston is passing through the upper port *f*, down the hollow of the valve *b b*, to the condenser, by the eduction-pipe *h*. In fig. 119, the steam distribution is shewn when the piston is at the top of the cylinder. The valve has left the lower port, which gives free communication between the condenser and the under side of piston; the steam is therefore rushing through it, down the eduction-pipe. The steam is entering from *g*, to the upper port *c*, and to the upper side of piston.

Fig. 117.

Fig. 118.

Fig. 119.

337. The arrangement of the mechanism of the beam-condensing steam-engine necessitates the adoption of a different

method of working the valves. The eccentric is fixed to the fly-wheel shaft, and the eccentric-rod is horizontal, instead of vertical, as in fig. 110; this is shewn at *d d*, fig. 116. In fig. 120, the other part of the valve mechanism is shewn; *d d* is the end of the eccentric-rod, corresponding to *d d* in fig. 116. The end of this is provided with a slot having a semicircular termination. This passes over the stud or pin of one end of a bell-crank lever *b*, which vibrates in the pedestal *a*. This bell-crank is fixed on a shaft, which is termed a *rocking-shaft* or *weigh-shaft*. The other arm of the crank *c* is attached to the end of a side-lever *f*, the other end of which is fixed to the cross-head fixed on the end of the valve-rod. A corresponding arrangement of levers is at the other side, fixed to the other end of the rocking-shaft and valve-rod cross-head. The right and left alternate motion of the eccentric-rod *d d*, gives an alternate up-and-down reciprocating movement to the side-levers *f g*, and to the valve-rod with which they are connected.

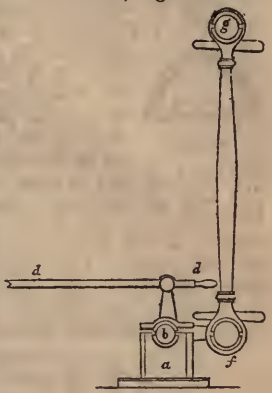

Fig. 120.

BOILERS.

338. The varieties of boilers introduced since the time of Watt have been very numerous. Those most generally used at the present time may be divided into two classes—the *flued cylindrical* and the *tubular*. The form known as the *wagon*, almost universally used in Watt's time, and for long after, is now nearly extinct. Boilers are now made of a cylindrical form, with flat or spherical ends—generally the latter. For high-pressure engines of comparatively small power, the boiler consists of a long cylinder with spherical ends, set in a furnace so constructed that the flame and heated air pass from the fire, which is placed at one end, through a series of flues, to the chimney; coming in contact, during its passage, with the bottom and sides of the boiler. For low-pressure pumping-engines, a class of boiler much used is that known as the *Cornish*. In this form, a cylindrical tube or flue is passed through the interior of the boiler, from end to end. The fire is placed within this flue, at one end; the smoke and heated

air pass along it to the further end, where they are divided into two currents—one of which passes along a flue at the side of the boiler, returning to the fireplace; the other passing along a flue at the opposite side—when they ultimately meet, and pass off by the chimney. When the draught is thus managed, it is termed a *split*-draught; when the current is not divided, but is made to pass round the boiler, till it enters the chimney, it is termed a *wheel*-draught. In either case, the object sought to be attained is to bring the heated air from the furnace or fire in contact with as much boiler-surface as possible, and to abstract as much of the useful heat, leaving only as much as will insure a good draught or upward current in the chimney. Fig. 121 will explain the arrangement of a flued cylindrical

Fig. 121.

boiler: *a a* is the outer case or boiler; *f f*, the internal flue covered with water; *d*, the fire-bars; *c*, the fire-bridge; *b b*, the brickwork supporting the boiler. In place of one flue, a form of boiler having two flues is now much, and is likely to be almost universally, used. Fig. 122 shews the arrangement:

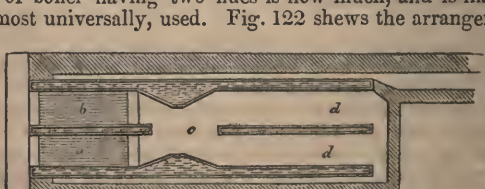

Fig. 122.

a b, the two furnaces, separated by a water-space; *c*, the mixing-chamber; *d d*, the two flues, separated by a water-space. One great advantage to be obtained by this form is, that alternate firing is easily carried out. By this method, the consumption of smoke is effected with considerable certainty. While the fuel in one furnace, as *a*, is in a state of high combustion, evolving little smoke, but chiefly highly-heated gases, the other furnace, as *b*, is supplied with green coal—the smoke

from which, meeting the gases from the other in the mixing-chamber *c*, is ignited.

339. In order to ascertain the condition in which the boiler is at work, as to its supply of water, the pressure of the steam, &c.—matters of much importance, as involving not only the economy, but the safety of the operation—a variety of appliances are attached to boilers. These we shall briefly notice; and first, as to the means for insuring a regular supply of water. To keep the parts of the boiler which are in contact with the heated air or flame covered with water, is the point to be attended to; at the same time, sufficient steam-space must be left in the interior. The proper level of the water in low-pressure boilers is maintained by the following apparatus:—A tube *a a*, fig. 123, is passed into the boiler, and continued within a few inches of the bottom. To the top of this a small cistern, *b b*, is attached, which is kept well supplied with water by means of the engine force-pump. A small valve, *c*, is placed at the entrance of the tube *a*; the spindle of this is attached by a movable joint to the lever vibrating on the centre *d*. An iron rod or wire, *f f*, is connected with one end of this, and led through a stuffing-box in the top of the boiler to its interior; a stone-float is attached to the end, at a height from the bottom of the boiler corresponding to the water-level. A weight, *e*, is connected with the opposite end of the lever *d*, to act as a counterbalance to the float. Supposing the water to fall in the boiler, the stone-float descends, depresses the end of the lever *d*, and raises the valve *c* out of its seat: this admits the water to pass from the cistern, down the tube *a a*, to the interior of the boiler. On the water rising to its proper level, the stone-float ascends, raises the end of the lever, and closes the valve *c*. The height of the tube *a a* must be proportioned to the pressure of the steam in the boiler; if the level of the cistern *b b* were too low, the steam would force the water up the tube, and open the valve *c*.

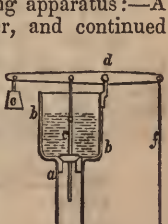

Fig. 123.

340. To ascertain the quantity of steam and water in the boiler, gauge-cocks are used. The tube of one of these, as *b*, fig. 124, is led into the interior of the boiler, and terminates at a point to the level of which the water should always be; the other tube *c* terminates in the steam space. Should the condition of matters in the

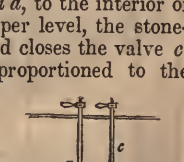

Fig. 124.

interior of the boiler be right, one of these cocks, when opened, should *always* blow off steam; the other, water. If both blow off steam, too little water is in the boiler; if water, there is too much. Another apparatus, generally attached to well-arranged boilers, is the water-gauge, shewn in fig. 125. Let *a a* be part of the boiler; *b b*, the proper water-level; a tube, *e*, communicates with the water-space, and another, *d*, with the steam-space. These again are connected by a strong glass tube; communication being effected between this and the interior of the boiler by means of the pipes *d* and *e*. Stop-cocks *f* and *g* open and close this communication at will. When these are opened, the water rises in the glass tube, to the same level as in the boiler; all the fluctuations of the water-level in the boiler are thus open to inspection through the medium of the glass tube. Should the pressure of the steam increase beyond the point considered safe, means are adopted to prevent any dangerous results. This is effected by means of the safety-valve. The construction of this, as generally used, is shewn in fig. 126. A pipe or box, *a a*, is bolted to the top of the boiler; a valve *c c*, to which the steam has free access, is placed in this. The spindle of this is connected by a jointed lever to the lever *d*, the centre of which is at *c*. A weight, *f*, regulates the pressure on the valve *c c*; the further it hangs from *d*, the greater the pressure on the valve. On the steam increasing beyond the point, it raises the valve *c c*, and escapes to the atmosphere; on the pressure decreasing, the weight *f* presses the valve *c c* into its seat.

Fig. 125.

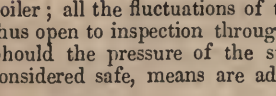

Fig. 126.

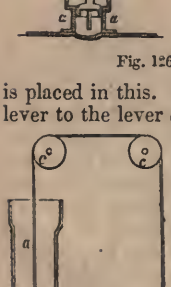

Fig. 127.

341. Still further to render the arrangements of the boiler efficient, and to make it in some measure capable of attending on its wants, the apparatus known as the *self-acting damper* is used in connection with the water-supply apparatus in low-pressure boilers. In the interior of the water-tube *a a*, fig. 123, a cylindrical float *b*, fig. 127, is suspended. A wire is taken from this, and passed over two pulleys *c c*, and is finally attached to the damper *d*, which is inserted in a frame placed at the entrance of the chimney.

The float *b* acts as a counterbalance to the damper *d*. On the

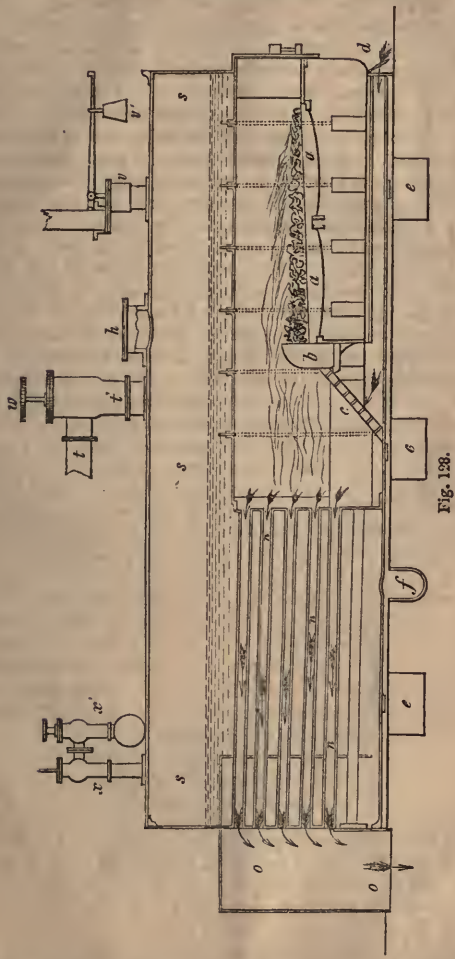

Fig. 138.

steam increasing in pressure, it presses on the surface of the

water in the boiler, and forces it up the tube *a*; this raises the float *b*, and allows the damper *d* to slide into its frame; this closes the aperture of the chimney—the draught is lessened—the intensity of combustion of fuel reduced—the steam is generated more slowly—the float *b* falls, and the damper *d* rises in its frame. Thus, by a series of risings and fallings of the float *b*, the production of steam is regulated.

342. A form of boiler adapted either for low or high pressure steam-engines, and now much used, is that known as the *multi-tubular*. We give, in fig. 128, page 101, a sectional elevation of one form of this variety: *a a*, the fire-bars; *b*, the bridge; the smoke and heated air, after passing from the furnace, rushes through the series of tubes *n n n*, placed within the boiler, to the chamber *o o*, communicating with the chimney. The sediment is withdrawn from the boiler by the tube *f*; *d* is a valve for admitting cold air to a flue leading to a divider *c*; the cold air, coming in contact with the smoke from the furnace, serves to ignite it, and thus prevent smoke. The steam-space is at *s s s*; it is led off to the engine through the pipe *t t*, furnished with a stop-valve, regulated by the hand-wheel and screw *w*; *h* is the man-hole door, by which access is gained to the interior for the purposes of cleansing; *v v*, the safety-valve; *x x'*, the water-supply apparatus adapted for high-pressure. We give a sketch illustrating this, known as the *differential feed*, in fig. 129: *a*, the tube entering the boiler; the water to supply the boiler is pumped into the spherical space *b b*; a valve, *c*, communicates with the tube *a*, and a second valve, *d*, with the space *d*; *e* is the spindle of the valves, connected with the lever vibrating on the stud *f*; *g* is the rod connected with the stone-float; *h*, the counterbalance-weight. A passage, *o o*, leads from the tube *a* to the space *d*. When the float falls, it raises the valve *c* out of its seat, and the water passes into the boiler. But suppose the pressure of the steam in the boiler forced the water up the tube *a*, it would have a tendency to open the valve *c*, and admit water, whether required or not: to prevent this, the passage *o o* is made; by this the water is forced into the

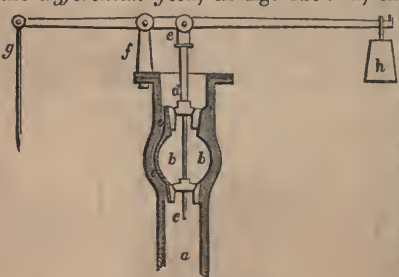

Fig. 129.

space *d*, and presses on the valve *d*. As the pressure is therefore equal on both sides of *c*, it remains in its seat.

343. The form of stop-valve used to regulate the supply of steam to the steam-pipe, is shewn in fig. 130: *a*, the part attached to the boiler; *b*, the pipe conveying the steam to the engine; *d*, the valve; *c c*, the valve-seat; the screwed spindle *e e* passes through a screwed stuffing-box; by turning the wheel *f*, the valve *d* is raised and lowered in the seat *c c* at pleasure. A similar form of stop-valve is used at the water-feed apparatus, at *x'*, fig. 128. The water is in the first instance pumped into *x'*, and passes therefrom to the part *x*, shewn in section in fig. 130.

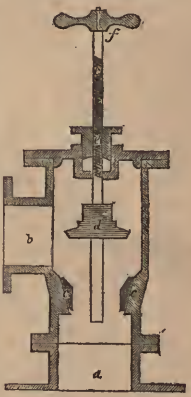

Fig. 130.

344. We have thus endeavoured, as briefly as possible, to present the reader with a clear explanation of the peculiarities of the modern steam-engine and its various appliances. We have endeavoured to do so in a popular style—our aim being merely to present a general outline of the subject. Some notice of this wonderful machine we deem essential in a work treating on Mechanics: this notice, however, we have made—like the other departments of the work of which it forms a part—merely elementary; leaving the reader interested in the subject to pursue his investigations with the aid of larger and more detailed works treating exclusively thereon.

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